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ABSTRACT

This final report on the relationship between orthographic characteristics and reading behavior consists of five chapters. The first chapter examines writing in its variety of forms in different cultures, noting that such differences can provide important clues to how the brain processes visual information. The second chapter addresses the issue of orthography and reviews results of cross-language research and comparative reading studies in order to achieve a better theoretical and practical understanding of the fundamental psychological processes of reading behavior, both in their acquisition and in their developed functioning. The third chapter describes three experiments that investigated the nature of deaf children's reading inability, while the fourth chapter critically examines the conceptualization between two experiments that presented words in the format of mixing upper and lower case letters to gather evidence for visual reading in skilled readers. The fifth chapter addresses the issue of orthography, reading, and higher cortical functions and examines how the brain adapts to orthographic variations across and within different languages. (HOD)

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A Final Technical Report on

RELATIONSHIP BETWEEN ORTHOGRAPHIC CHARACTERISTICS AND READING BEHAVIOR

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Chapter One

The First Two R's

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THE FIRST TWO R'S

Writing has been invented in a variety of forms in different cultures, though all major writing systems are based on the spoken language. Differences among these systems provide important clues to how the brain processes visual information.

by Ovid J. L. Tzeng and William S-Y. Wang

> "School days, school days;
> dear old golden rule days;
> reading and writing and 'rithmetic;
> taught to the tune of a hickory stick;..."

The last line of this popular children's song calls to mind the old fashioned classroom with its stern discipline which has by now all but vanished from the American scene. It also highlights an interesting fact--that reading and writing are skills that do not come naturally, the way speech does. Typically, by school age, a child has effortlessly soaked up from his environment all the basic structures of the spoken language, whether it be English, Chinese or Telugu.

Learning the written language, however, is frequently quite an arduous process. Millions of people in the world are illiterate for lack of adequate opportunity. A significant number of American children have problems with reading and writing, even with the help of the best facilities. This contrast between the two forms of language (speech versus script) is all the more striking given that written language is invariably based on the spoken.

In evolutionary terms, speech emerged considerably earlier, many hundred thousand years ago, when our ancestors roamed the grasslands for food and searched out caves for shelter. Agriculture began to replace the life style of the hunter some twelve thousand years ago. The earliest precursor of writing appeared shortly after, even though these did not develop into full fledged writing systems until several thousand years later.

Clay tokens have been found at sites along the Iran-Iraq border, varying in size and shape as well as in marks and perforations. They date back ten millienia or more, and were used for simple record keeping. It has been proposed that these tokens gave rise to the Sumerian ideographs (Scientific American June 1978). Incisions found on Neolithic pottery from some several thousand years ago at Banpo, China, are believed to be the direct precurosors of the Chinese script. These too apparently were a response to the needs of agricultural life.

Whereas the sounds of speech fade rapidly in time and space, written message endures and can be carried from place to place. The invention of writng, which occurred many times independently in distant parts of the world, including some that have emerged in modern times, must rank among mankind's highest intellectual achievements. Without writing, human culture as we know it today is inconceivable.

All of the major systems of writing are based on the spoken language, though in ways which are importantly different from each other. To see these differences more clearly, we need to clarify what is meant by the following units which are used in all spoken languages; feature, segment, syllable, morpheme, and word. A writing system, or a script, may be categorized according to how these five types of units are represented in its symbols. Actually, most writing systems are really composite in that they typically correspond to two or more different types of units.

Features are elementary components of individual speech sounds, but not full speech segments themselves. Some familiar examples where diacritic symbols in the script correspond to phonetic features in the speech are the cedilla in French which modifies the letter c changing it from a k sound to an s sound (as in ca); or the tilde in Spanish which changes a dental n sound into a palatal n sound (as in senor).

The familiar type of alphabetic scripts that prevail in the West today are roughly based on the segment. That is, a letter in the script corresponds to a consonant or vowel segment in the speech. The shape of the letters may vary, of course, such as between the Cyrillic and Latin alphabets. The correspondence is seldom perfect. So in English, the single letter x may represent two segments ks, while the two letters th actually represent only one segment. Nonetheless, the ideal match is one letter for one segment. Another aspect of such scripts is that words, rather than morphemes or syllables, are separated by spaces.

In speech, the segments combine to form syllables. A syllable is a natural unit of pronunciation, typically containing a vowel and its surrounding consonants. Writing systems where the symbols correspond to syllables are called syllabaries. An example of a syllabary is the Japanese kana; for instance the symbol (***) represents the syllable ka.

An interesting script that makes composite use of feature, segment and syllable is the hangul, devised in Korea in the middle of the 15th century, during the reign of King Sejong, (See Figure 1). While the letters correspond largely to speech segments, there is considerable organization in the design of these hangul letters to reflect their phonetic features. Furthermore, these letters are stacked against each other into square frames, each frame corresponding to a syllable.

So in contrast to English, where the words are separated by spaces, in hangul it is the syllables that are written apart. In a sense, hangul is simultaneously an alphabet and a syllabary. The Korean hangul is an ingenious invention and deserves much further study from a psychologuistic point of view.

The Chinese script is the only major writng system now in use where a significant number of the symbols, called logographs, preserve a direct relation to the morphemes themselves rather than to the pronunciation of these morphemes, (Scientific American, February 1973). Morphemes are the basic units of meaning which combine to make up words. For instance, the words boy, boyish and boyishness contain one, two and three morphemes respectively, even though each is a single word.

A few logographs are derived from stylized pictures, such as a simple drawing of a mountain or of a bird. Through many centuries of simplification and standardization of the script, however, the likeness is no longer obvious. Some other logographs are made up from pieces from which the meaning can be inferred. The symbol for "good," for instance, is a combination of "woman" and "child." The logograph for "inch" is formed from that for "hand" with a dot below showing the location of the pulse on the wrist; the inference here is that the distance between the two is an inch.

However, the great majority of logographs in the Chinese script, over 80%, are formed on a different principle. They have two parts. One part refers to the semantic category of the morpheme, while the other part refers to the syllable with which the logograph is pronounced. As an example, the left half of the logograph for "ocean" means "water," while the right half indicates that it is pronounced with the syllable "yang." So these logographs have a composite function--they may be best characterized as being morpho-syllabic.

One of the major activities in learning to read is exploring the correspondence between the written script and the spoken language. Since the correspondence between the printed symbols and speech in an alphabetic writing system differs from that in a logographic system, skilled readers of either system develop different processing strategies in order to meet different cognitive requirements. These strategies are so entrenched in the processing system after many years of constant practice that their activation becomes all but automatic.

For example, a reader of English cannot keep from applying an abstract rule system to tackle the letter-segment correspondences in the printed words, whereas a reader of Chinese automatically activates a spatial-configuration scan at the logographs. Thus the diversity of writing systems provides excellent opportunities for investigators of human cognition to examine how children of different language backgrounds meet various task demands imposed by different writing systems. Once we understand the flexibility and limits of such adjustments, we wil be in a better position to theorize about basic reading processes and to design remedial programs to help reading disabled children.

It has been noted for quite some time that a fluent reader cannot activate the semantic code of a printed word once he sees the word. The phenomenon can be demonstrated very easily with an experimental procedure called the Stroop interference task. In essence, color names are written in an ink of a different color (e.g., "GREEN" written in red ink). In the test condition, the readers are required to name the color of the ink. In the control condition, the readers are required to name the colors of a series of different color patches. (See Figure 2).

The results are usually clearcut. The time it takes to name a series of colors in the test condition is much longer than the time it takes to name a series of color patches in the control condition. This is a robust effort that has been found in every language examined.

An interesting question arises at this point: would the magnitude of the interference (i.e., the time to name the color of the color word minus the time to name the color of the color patch) differ across the various scripts? The answer is a decisive YES: logographic scripts produce greater interference than both syllabaries and alphabets.

The Stroop task can be extended to pairs of languages. For a long time researchers have noted that for a bilingual reader the interference is reduced if the printed color words and the responses are in different languages. We replicated this finding in our laboratories for several pairs of languages.

Our results further show that there is a systematic relationship between the interference and the degree of similarity between the two scripts.

Insert Table 1 about here

This regularity can be seen in the summary data in Table 1. The ordering of the last three categories is particularly revealing. Why should switching between Spanish and English produce a lesser interference than that between French and English? It is certainly not a priori obvious that Spanish and English are orthographically more dissimilar than French and English (or German and English). However, if we examine the spellings of color terms across these languages, as shown in Table 2, then the difference between Spanish and English spellings of these color terms is easily seen to be the greatest.

Insert Table 2 about here

The regularity of this finding across these several scripts suggests that the linguistic code used in reading cannot be simply semantic. Rather, the code contains semantic, phonological, as well as orthographic information as an integrated whole.

Can the above results be an artifact of the speech activity naming the colors aloud? To eliminate this possibility, we ran another type of experiment which was in essence a variant of the Stroop task; but it requires no oral response. A pair of numbers (e.g., 6 and 9), were projected onto a screen and readers were asked to choose the larger number by pressing a key. In the neutral condition, the two numbers are written in equal size. In the incongruent condition, however, the larger number is written in a smaller size than the lesser number. That is, the "6" appears larger on the screen than the "9" (See Figure 3).

It has been known that a Stroop-like interference can be demonstrated in that it takes longer to make a correct choice in the incongruent condition than in the neutral condition. What would happen if we used spelled words instead of Arabic numerals (e.g., "SIX" and "NINE")? Oddly enough, the interference disappeared when the experiment was done for English. However when a parallel experiment was done for Chinese, using logographs, instead of alphabetic letters, the interference was again observed.

We carried the experiment a step further. A group of Chinese-English bilingual readers (with Chinese as their first language) participated in the next number-vs-size interference task. For these readers, all three types of stimuli were used. Arabic numerals, English spelling, and Chinese logographs. As before, we observed the interference with both Arabic and Chinese stimuli. Unexpectedly, however, these readers also showed an interference with the English spelling as well (See Figure 4).

How do we account for this last finding? Could this simply be due to the fact that English for them is a language acquired later in life? Or, is it because the processing strategy for logographs had been transferred to alphabetic spelling? To choose between these two hypotheses, we next worked with a group of Spanish-English bilingual readers. They did the number-vs-size task: once with Arabic numerals, once spelled in English, and once spelled in Spanish (See Figure 5).

The results are unequivocal. The interference occurred only with the Arabic numerals. Neither Spanish nor English spelling produced any interference. So the interference observed in the English word condition for the Chinese-English bilingual readers was not due to the factor of second language learning. Otherwise, we should observe a similar interference effect with the Spanish-English bilinguals. The remaining hypothesis, then, is that these subjects had transferred their reading habits from logographs to English spelling.

The evidence we have reviewed so far, from both the color and number Stroop experiments, supports the contention that the script-speech relations underlying different types of writing systems play an important role in reading behavior. A reader of a particular script must assimilate the orthographic characteristics of that system. That is to say, if the configurational property is important in the logograph, then the reader has to pay special attention to the spatial layout of each and every element it contains. As a consequence, we should expect to observe a greater memorial activity in the visual system during processing of logographs than of alphabetic script.

With this hypothesis in mind, we set out to compare the memory performance of native English readers and native Chinese readers in a serial recall task. A series of 9 items were presented to subjects either auditorily via a tape-recorder or visually via a slide projector. (In the visual presentations, the items were in either English spelling or Chinese logographs.) The subjects were asked to recall the 9 items according to their positions in the series. The probability of recall was plotted according to the item's serial position. These data can be seen in Figure 6.

The memorial performance of the American readers is consistent with previous findings from other laboratories. Auditory presentations usually produce better recall performance than visual presentations for the terminal items. The data from the Chinese readers also show that the auditory presentation is superior to the visual presentation for the last two items.

The interesting difference between the two groups is this. The Chinese readers recalled the non-terminal items consistently better when these were presented visually, whereas no such difference was found for the American readers. This superiority of visual presentation for Chinese readers holds regardless whether the recall itself was an oral or written response. This finding suggests visual memory is involved more critically in the processing of logographs than of alphabetic scripts, thus confirming the hypothesis raised earlier. In fact, it further suggests that the influence of the sensory characteristics of the visual information may not be restricted to the very early stages of processing, and that reading different kinds of script taps into different memory mechanisms which are themselves modality specific.

This greater involvement of visual memory in processing logographs can also be demonstrated with a different type of experiment. In recent years, experimental psychologists have been using a special apparatus called the tachistoscope (or T-scope) to investigate the specialization of functions and capabilities of each of the two cerebral hemispheres. Basically, a T-scope is a device which enables the experimenters to present visual images for very brief periods of time. When a subject fixates on a point in the center of a lighted square within the T-scope, each visual half-field projects to the contralateral hemisphere. So, for example, stimuli presented to the right visual field (RVF) are first processed in the left hemisphere, and stimuli in the left visual field (LVF) to the right hemisphere. By correlating the levels of performance on different tasks to the stimulus locations, most investigators agree that the left hemisphere is specialized for sequential-analytic ability whereas our right hemisphere is specialized at Gestalt-holistic match of visual patterns.

In our laboratories, the visual half-field technique has been applied to study the process of word recognition in various scripts. The results are hardly surprising. For alphabetic scripts, such as English and Spanish, a RVF superiority is consistently found, suggesting a greater involvement of left hemisphere functions. This RVF superiority obtains as well for scripts like Arabic and Hebrew, eventhough here the letters run right to left across the page. In contrast to these scripts, a LVF advantage is observed with

Chinese readers when presented with single logographs, suggesting a greater involvement of right hemisphere functions.

The most striking results come from experiments with Japanese, where a word can be written with either the symbols of a syllabary, called kana, or with logographs, called kanji (which literally means Chinese characters). With native Japanese readers we were able to hold the variables of subject, word and writing direction constant across experiments. Under these circumstances, a LVF advantage was found for the recognition of single logographs, whereas a RVF superiority was found for the recognition of words written in kana. Apparently two different perceptual mechanisms are activated to handle two distinct types of written symbols.

However, it is important to emphasize that these data should not be taken to suggest that Chinese and Japanese readers store thousands of logographs in their right hemispheres and leave their left hemispheres to handle the spoken language. Rather, what has been demonstrated in all these experiments is that a greater demand of visual processing is inherent in the task of recognizing logographs, and that meeting such a demand requires a greater involvement of the right hemisphere.

It is also worth noting that recognizing the single logograph is only a tiny step toward sentence comprehension in reading. Chinese and Japanese readers have to put several logographs together to form a "inguistic" word, e.g., the three characters AAA BBB CCC for the word library, literally picture - book - hall. Thus the task demands for the recovery of meaning in a word go much beyond just simple recognition of individual logographs. At this stage of processing, a greater involvement of left hemispheric function is called for and one would expect a RVF superiority in the T-scope experiment for such tasks. The reversal from a LVF superiority to a RVF superiority in reading logogrpahs was exactly what we found in another series of experiments.

This suggests that in reading different scripts, the initial perceptual pathways may be different, but later processing may converge on similar linguistic processes. It is of great theoretical importance to ask where the convergence occurs and what is the nature of the resulting linguistic code.

From findings made in our laboratories and in other laboratories, the answer to the above question seems to be clearcut. As soon as our eyes fixate on the print, the visual information, combined with contextual information is automatically transformed into an abstract "word" code which carries phonological, orthographic (e.g. spelling patterns), and semantic information. There is no dispute among psychologists concerning the availability of the latter two types of information. There is a controversy, however, over whether the phonological information is a pre-lexical or post-lexical product, or whether it is necessary at all.

We prefer to think that the recoding from the visually presented print into a phonological format is an automatic and inevitable process. Recent experiment on word recognition have yielded much evidence for the inevitable access of phonological information. It can be shown that the phonological anomoly interferes with word recognition at a very early stage of processing. This is true for the recognition of Chinese words (not single characters). It is also true for the recognition of Hebrew words, in which vowels are usually deleted in their spellings. And in Serbo-Croatian writings in which words can be written in either Roman or Cyrillic letters, readers automatically recode the printed symbols such as POTOP into two different phonological formats (means "inundation" and "rotor" in Roman and Cyrillic reading, respectively), even when they are engaged in only one way of reading.

These results tell us that no matter in what types of writing systems, a reader always has access to the phonological information. It is not true that reading Chinese logographs does not require such information. A native Mandarin speaker has difficulty reading a Cantonese newspaper printed in Chinatown. It may be more difficult for a Chinese or Japanese child to establish automaticity in grapheme-sound conversion due to the fact that phonemic information has not been specified in the characters. That is why chanting plays so important a role in the early acquisition of reading logographs in both China and Japan.

So far we have been concerned with fluent readers of various writing systems. It has been suggested that different neurolinguistic pathways are organized to transform different written scripts into a common linguistic code. Can this suggestion be corroborated by neurophysiological data? Happily, the answer is a positive one. In general, lesions in the temporal cortex are associated with greater impairment of reading and/or writing of scripts that are phonemically based, whereas lesions in the posterior, occipito-parietal areas are associated with greater impairment in logographic scripts.

And again, the most striking data come from the examination of Japanese aphasic patients with respect to their ability to use kanji and kana scripts. Sumiko Sasanuma and her co-workers in Tokyo have reported that the ability of Japanese aphasic patients to use these two types of scripts can be selectively impaired. Impairment of kana processing emerges typically in the context of Broca's aphasia while impairment of kanji processing in characteristic of Gogi (word meaning) aphasia. Thus pathological data seems to match rather nicely with those of normal readers, an unusual feat in our search of the biological basis for cognition.

The interactions between task demands imposed by various scripts and the patterns of visual field effect in T-scope experiments show, on the one hand, the flexibility of our information processing system to adapt to various orthographic principles. But of equal importance they reveal the cooperative and integrative nature of our neurolinguistic activities in reading.

In recent years the discovery of hemispheric specialization has lead many students of the brain to characterize the two hemispheres as "dominant vs. nondominant", "Western vs. Eastern", "active vs. resting", etc., as if the two hemispheres are two separate brains with two separate minds. Such a characterization of our brain function is certainly misleading. There is no doubt that hemispheris specializations are important properties of our brain. However, it is the collaboration and compensation of various neural components working together as an integrated whole that is the most important hallmark of human cognition.

The diversity of scripts and the associated information processing strategies reveal the intricate symbol-thought interaction which touches the very core of the nature of cognition. Inevitably, we are led to wonder to what extent are the ensuing differences in cognitive styles ultimately responsible for more global differences among cultures. It seems that, here again, we are at once the creator and the product of our media.

Figure legends:

1. The Korean Hangul writing system was devised in the middle of the 15th century during the reign of King Sejong. This system makes more systematic use of the phonetic features of the spoken language than any other orthography. King Sejong continues to be widely revered today for this invention. These photographs, taken by Dr. Namgui Chang, are of King Sejong's status, which sits at the center of the Duksu Palace Gardens in Seoul. On the T shaped plaque in the inset, the 17 symbols in the top row represent consonant sounds, the 11 symbols in the bottom row represent vowel sounds.

2. The Stroop effect is used to measure the amount of interference that words have on naming objects. You are invited to name the colors of the blocks in the top two rows as quickly as possible. Then try to name the colors of the English words in the next two rows as quickly as possible: do not read the words! The greater difficulty in performing the second task is an index of how directly the written words are coupled to their meanings. The lower rows are written in Chinese, Spanish and Japanese kana.

3. In this figure, the smaller number is written in a larger size. This incongruence between the number and its size causes a delay in the time the subject needs to decide which number is larger. However, the amount of delay varies accoridng to which script the numbers are written in. The numbers illustrated here are written in Arabic numerals, in Englihs, Chinese and Spanish.

4. This figure shows the performance of Chinese readers in making number judgments when the stimuli are presented in different scripts. See discussion in text.

5. This figure shows the reaction times of Spanish readers in making number judgments when the stimuli are presented in different scripts. See discussion in text.

6. The figure shows the results of the serial position effect as it differs between English and Chinese. In both languages, recall of the last items in the series is better in the auditory modality. However, the early items are recalled better in Chinese when they are presented visually, whereas in English there is no such difference. This finding highlights the influence of the script on memory processes.

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Estimated reduction of Stroop interference effect as a result of switching languages for various types of bilingual subjects. Data were taken from Dyer (1972), Preston and Lambert (1979), and from Tzeng, Fang, and Alva (in press).

Chinese-English	168 msec.
Japanese-English	
Kanji	144 msec.
Kana	120 msec.
Hungarian-English	112 msec.
Spanish-English	78 msec.
German-English	36 msec.
French-English	33 msec.

Table 2

Color Names Used in These Experiments Across Languages

English	Red	Blue	Green	Brown
German	Rot	Blau	Grün	Braun
French	Rouge	Bleu	Vert	Brun
Spanish	Rojo	Azul	Verde	Cafe
Hungarian	Piros	Kék	Zöld	Barna
Chinese	紅	藍	綠	褐

	▨ ▨	▨ ▨	▨ ▨	▨ ▨
English	PURPLE RED	BLUE PURPLE	GREEN RED	GREEN GREEN
Chinese	紫 綠	紅 蓝	綠 紅	蓝 紫
Spanish	VERDE AZUL	AZUL MORADO	MORADO VERDE	ROJO ROJO
Kana	あカ あお	むらさき あか	あお みどり	みどり むらさき

6

9

NUEVE

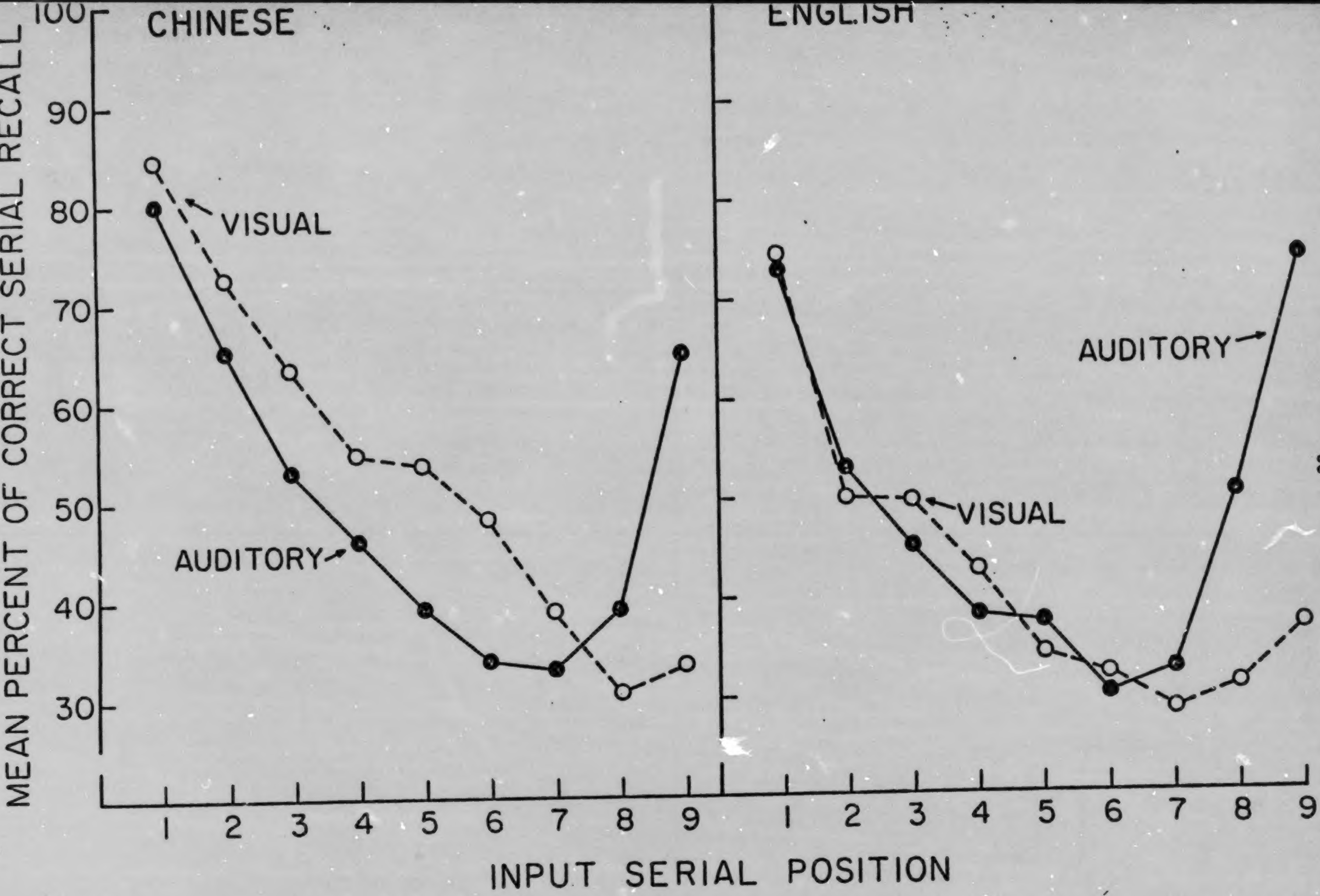
SEIS

SIX

NINE

九

六


CHINESE
ENGLISH
MEAN PERCENT OF CORRECT SERIAL RECALL
100
90
80
70
60
50
40
30
VISUAL
AUDITORY
AUDITORY
VISUAL
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
INPUT SERIAL POSITION

Chapter Two

Cognitive Processing of Various Orthographies

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Introduction

In recent years, reading research has become a significant interdisciplinary endeavor with contributions from such diverse fields as anthropology, artificial intelligence, cognitive psychology, educational psychology, linguistics, and neurolinguistics. The concerns are not only with how we acquire the skill of fluent reading, but also with the behavioral and social consequencies of the success or failure to become literate in a technology-expansion society. But for experimental psychologists, such a revival interest in reading research has a special meaning. Historically, the systematic study of the processes involved in reading can be traced back to Wundt's laboratory where sensation, perception and reaction time experiments became some of the foremost concerns of a newly founded discipline. In those early years, basic reading research was considered to be one of the major tools of analyzing the contents of mind. In fact, shortly after the establishment of the first experimental psychological laboratory, James McKeen Cattell, Wundt's first American student, wrote his dissertation on the topic of reading. In 1908, Edmund Burke Huey published his monumental work, The Psychology of Reading and Pedagogy (Huey, 1908, 1968), in which most of the reading research of this early period was carefully and scholarly summarized. Oddly enough, soon after the publication of this book, the proliferation of basic research in reading suddenly came to an end and experimental psychologists' interest in mental processes gave way to the analysis and specification of the functional relationship between Stimulus and Response in behavioral act. Furthermore, verbal learning experiments in the Ebbinghaus tradition became the focus of research on the analysis of verbal behaviors. Even within the education circle, investigators were preoccupied with a concern for assessment and as

Kolers commented in his introduction to the 1968 reprinting of Huey's book, "remarkably little empirical information has been added to what Huey knew" (Huey, 1908, 1968, p. xiv).

The return of interest in basic reading research was brought by several important forces. First, the renaissance of the Cartesian idea of "innateness" led by Chomskian transformational linguists shifted researchers' attention from descriptions of surface structure toward analyses of deeper structures in natural languages. Second, advances in computer technology in both hardware and software created a new research technique, namely computer simulations of the higher mental processes such as problem-solving, thinking, and comprehension. Comparisons of such "artificial intelligence" on the one hand and "natural cognitive behaviors" on the other have continued to generate insights into our understanding of *understanding*. Third, the psychochronometric procedure (i.e., reaction time experiments), abandoned after condemnation of Donder's subtraction method, has developed to a level of sophistication such that its reliability can be established independent of the stochastical processes involved (Sternberg, 1970; Posner, 1978). Such procedures have been proven to be useful for experiments of word recognition, lexical decision, sentence verification, and inferential processes in comprehending texts. Furthermore, reaction time experiments are usually accompanied by complicated models of information processing which attempt to specify basic internal stages as well as their interactions during reading. Fourth, a great deal of knowledge concerning different levels of speech signals has been accumulated in the experimental analysis of speech perception and production. Such knowledge enables investigators to more precisely specify the script/speech relationship embedded in various writing systems and to examine the role of speech in processing printed materials (Liberman, Liberman, Mattingly, & Shankweiler, 1980). Fifth, and possibly most important, Rudolf Flesch published a book in 1955 called Why Johnny Can't Read. This book had an enormous impact on the public and the issue of reading problems soon became a national concern. Consequently, federal funding for basic research related to the improvement of education was appropriated by Congress, with the goals of strengthening the scientific and technological foundation of education (Venezky, 1977). Undoubtedly, the availability of financial support plus the cognitive reorientation within experimental psychology will sustain a vigorous pace in basic reading research, hopefully with many fruitful results.

While the experimental research in reading is gaining its momentum, and rigorous and ingenious experiments are being designed to investigate basic reading processes from letter identification to text comprehension, an important question should be raised: Why has the issue of orthography never been addressed in the discussion of reading and its acquisition? Certainly, English is not the only written script available for reading. People of other languages have been reading other types of scripts which bear very differet script-speech relationships as compared to the alphabetic principle of English script. What effects of these orthographic variations may have on basic reading processes and on the acquisition of reading skills has not been systematically investigated. Conceivably, depending on the level of spoken language a certain type of orthography attempts to transcribe, readers of that orthography may be subject to different task demands. Thus, the only way that we may hope to achieve a full understanding of reading processes in particular and of human cognition in general is through a thorough comparative reading research across different spoken and written languages. The purpose of this chapter is to give a general review of the issue of orthography and its relation to reading. In the following sections, I hope to provide a *missing link* for experimental psychologists' research on reading.

The Issue of Orthography

Ever since Rozin, Poritsky, and Sotsky (1971) successfully taught a group of second-grade non-readers in Philadelphia to read Chinese, the question has been repeatedly raised: If Johnny can't read, does that mean Johnny really can't read in general or Johnny just can't read English in particular? To the reading specialists, educational psychologists, and cognitive psychologists who are interested in the visual information processing of printed materials such a question is of empirical, practical, and theoretical importance with respect to the understanding of reading behavior. At the empirical level, is it true that some writing systems are easier to learn than others? At the applied level, what degree could reading disorders such as dyslexia be avoided because a certain writing system happens to be used for a certain type of spoken language? At the theoretical level, one must start to untangle the relations between scripts and speech. Research efforts should be directed toward uncovering strategic differences at various levels of information processing (e.g., feature extraction, letter identification, word recognition, etc.) with respect to the reading of different writing systems. These analyses may result in a new form of linguistic determinism (cf. Scribner & Cole, 1978; Tzeng & Hung, 1980).

The invention of written symbols to represent spoken language was a great achievement in the history of mankind. With the advent of writing, communication was expanded and the limitations of space and time (which are usually imposed upon oral communication) were overcome. There have been many writing systems for many different types of spoken languages. The basic design principles can be divided into two different categories. One category includes a progression from the early semasiography, which expresses a general idea in picture drawings rather than a sequence of words in a sentence, to logographs with each symbol expressing a single particular morpheme. The concept underlying the development of this type of orthography is to map the written symbols directly onto meaning. The second category of writing system includes a progression from the rebus system (a representation of a word or phrase by pictures that suggest how it is said in the spoken language, e.g., for idea) to syllabaries and, finally, to the alphabet. The concept behind this type of orthography is sound writing. Undoubtedly, the evolution and persistence of a certain type of writing depends to a great degree on the special characteristics of its corresponding spoken language (a review of the development of various types of writing systems can be found in Hung & Tzeng, in press). Since spoken languages differ considerably, diversity in writing systems is to be expected.

The diversity of writing systems raises an important question: Whether or not acquisition of reading skill is facilitated or hindered by how the spoken language is represented in print. This question has become of major concern among reading specialists (e.g., Gibson & Levin, 1975; Gleitman & Rozin, 1977; Liberman, Liberman, Mattingly, & Shankweiler, 1980) as well as cognitive psychologists who are interested in the effect of orthographic differences on visual information processing (Biederman & Tsao, 1979; Park & Arbuckle, 1977; Lukatela & Turvey, 1980; Tzeng & Hung, 1980; Tzeng, Hung, & Garro, 1978; Tzeng, Hung, & Wang, 1977). It is not unreasonable to conjecture that human information processing strategies may differ because the information is presented in different formats. For example, it has been suggested that the meaning of words and of pictures are recovered via different processing routes (Paivio, 1971). Thus, depending upon how meanings are represented in print (i.e., what type of writing system is used), a reader may have to develop different processing strategies in order to achieve reading proficiency. By comparing the experimental results of reading behavior across languages as well as across different writing systems, we should be able to gain some insights into the various intricate processes involved in reading.

The present paper will address the issue of orthography. Its purpose is to briefly review results of cross-language research and comparative reading studies in order to achieve a better theoretical and practical understanding of the fundamental psychological processes of reading behavior, both in their acquisition and in their developed functioning. With the assumption that different orthographies may encourage the use of different processing strategies (in fact, Hung & Tzeng, in press, provide much needed empirical evidence to support this assumption), we can easily appreciate the general advantage of such cross-language and cross-writing-system studies. By studying the processes used to read and to learn to read in each writing system, we can learn what the range of possibilities is. Knowledge of the possible processes used would be of theoretical interest to those who try to build theories of cognitive processes from reading research (e.g., Morton's logogen model, 1969). It would also be valuable in applications such as the modification of orthographies (Grimes & Gordon's discussion of problems encountered in constructing written languages for many American Indian languages, 1980). Furthermore, delineating the similarities and differences of reading processes between different writing systems will help to build an efficient reading instruction program which will benefit those bilingual children (recent refugees and other minority children) who are initially or simultaneously taught to read in writing systems other than English orthography. With these general statements in mind, let us now examine various grapheme-speech mapping relationships embedded in different types of orthographies and see how much orthographic variations affect the processing strategy of both beginning and fluent readers.

Relations Between Script and Speech

The relationship between written scripts and spoken languages seem so close that one would expect that anyone who is able to speak should be able to read. This is simply not the case. For all normal children, spoken language seems to require no special effort to learn. On the other hand, learning to read requires a relatively long period of special training and depends heavily on intelligence, motivation, and social-cultural factors. Even with so much effort being directed toward the acquisition of reading skills, not every child is blessed with the ability to read. Two psychologists of reading have summarized the state of affairs by saying, "The problem with reading is not a visual perceptual problem; the problem is rather that the eye is not biologically adapted to language" (Gleitman & Rozin, 1977, p. 3).

There is a general concensus that written languages evolved much later than spoken languages and that, in some way, the former attempted to mimic the latter. In fact, except for the earlier semasiography (dating back at least as far as 20,000 B.C.) which used pictorial representations to refer to meaning directly, most writing systems of the world today are parasitic, in various forms, on their corresponding spoken language. Since their development is largely based on speech, the scripts are all correlated with the preexisting units of the spoken languages. But the exact nature of this correlation varies across languages. That is, since there are many levels of representation for a spoken language, the transcription of visual symbols into the spoken language can be achieved in many different ways. Let us examine these relationships more closely.

Linguists commonly recognize three classes of phonetic segments: phones, phonemes, and morphophonemes (in order of increasing abstracteness). The segments group together horizontally into larger sequences: the mora and the syllable. These distinctions can be seen in the Japanese Kana script. For example, at the phoneme level, an utterance like "komban" has 6 phonemes represented by six different Roman letters. At a more concrete level, this same utterance contains 2 syllables but 4 moras, because each of the nasal consonants counts as an additional mora. Thus, the word is written with 4 Kana symbols such as . The corresponding Kanji, however, contains just 2 logographs such as , since Chinese script is based on syllables. These different script-speech relationships have important psychological implications for the learner. Recent speech perception research indicates that syllables are the smallest coherent units of speech: they tend to be physically undissectible, they are the smallest pronounceable units of speech, and they may be produced in preplanned units (Liberman, 1970). Therefore, grapheme-speech mapping at the syllable level should be less abstract than that at the level of moras or at the level of phonemes. Moreover, it has been reported that few reading disability children are observed in writing systems with concrete script-speech relationships such as the Japanese syllabaries and Chinese logographs (Makita, 1968; Tzeng & Hung, 1980).

If we look back at the history of writing, we soon discover that the appearance of various types of writing systems proceeds in a certain direction. In a sense, the transcription initially starts at the deepest level, the conceptual gist (e.g., picture drawings), then gradually shifts outward to the surface level, the sounds. At each step, the unique and concrete ways of representing meaning give way to a smaller but more general set of written symbols. In other words, the efficiency of writing is achieved at the cost of sacrificing the more direct link to the underlying meaning, and, consequently, the grapheme-meaning relationship becomes more and more abstract.

The traditional classification of orthographies into logographic, syllabic and alphabetic modes captures three types of script-speech mapping relationships. For our present purposes, we will review the essentials of these relationships, however, a detailed and in-depth analysis of such relationships can be found in Hung and Tzeng (in press).

Logography represents speech at the level of the morpheme rather than the word, so that each logogram stands for the smallest meaningful unit, and its form, therefore, remains constant regardless of syntactic structure. That is, grammatical marking elements, such as tense, number, gender, and so on, are introduced by adding other morpheme characters rather than modifying the form of a particular character. For example, in Chinese logographs, *go*, *went*, and *gone* are expressed by exactly the same character 去 , and both *ox* and *oxen* are expressed by the single character, 牛 . This perceptual constancy must provide a certain advantage over those writing systems, such as the English alphabet, which require the marking of grammatical inflections at the word level. Thus, the learning of a logographic system may have initial success as long as the characters to be learned are kept distinctively different. As more characters are introduced, however, they are bound to have similarities to the previously learned characters (after all, the number of basic strokes in Chinese character formation is only eight!). Whatever initial cues a young reader employs tend to fail as more characters are learned, confusion sets in, and learning is disrupted until other memory strategies can be used (Samuels, 1976).

The syllabary represents speech at the level of the syllable, a perceptually identifiable unit with a reduced set of symbols. For a beginning reader, the match between each symbol and each perceived sound makes the translation of visual arrays into the speech code much easier. The concept of mapping the secondary linguistic activity (i.e., reading) onto the primary linguistic activity (i.e., speech) can be acquired earlier through direct perceptual-associative links. However, the initial success of learning a syllabary starts to collapse as soon as a large number of lexical items are learned and the problem of homophones sets in. For example, confusions over segmentation (corresponding examples in English would be *to-gether* vs. *to-get-her*; *a-muse* vs. *am-use*, etc.) tend to pile up during ordinary reading (Suzuki, 1963). Special processing strategies are required with great demands on the reader for the linguistic parsing of a syllabary text (Scribner & Cole, 1978).

Finally, an alphabetic writing system represents speech at the morphophonemic level such that the grapheme-sound-meaning relationship is opaque. This requires a highly analytical processing strategy in order to unpack the meaning encoded in words that are composed of a still further reduced set of symbols. The abstractness of such a multi-level representation may be optimal for fluent readers (Chomsky & Halle, 1968). However, it poses a great deal of difficulty for those beginning readers whose cognitive ability has not yet reached the level necessary for extracting the orthographic regularities embedded in the written words.

There is also an important contrast between logographic and alphabetic scripts with respect to how symbols are stacked together to represent the spoken language graphically. For example, in English script, spaces are largely determined on the basis of words. *Man*, *gentleman*, *gentlemanly*, *ungentlemanly*, and *ungentlemanliness* are each written as a single word, even though the last word contains 5 morphemes while the first word contains only 1. In Chinese script, on the other hand, the spacing is based on morphemes and each morpheme is in fact a syllable. So, a word like *tricycle* has three morphemes in Chinese (three wheel vehicle) and is therefore written with 3 characters, 三輪車, and read as three distinct syllables. Perceptually, the grapheme-sound mapping in Chinese is discrete while in English script the relation is continuous and at a more abstract level.

The grapheme-sound mapping in these two languages may have different implications for the beginning readers of these two scripts. For Chinese children, the written array is dissected syllable by syllable and thus has a one-to-one correspondence with the syllabic boundaries of the spoken language.

Because of the multi-level representation, a reader of English, on the other hand, may have to go through a morphophonemic process in which (a) words are first parsed into morphemes and then (b) symbol-sound relationships can apply (Venezky, 1970). Furthermore, phonological rules are necessary in order to derive the phonetic form (e.g., to get /sain/ for sign). These processes are very abstract and may, therefore, be quite difficult for the beginning reader.

As we look back at these historical changes, we see that the evolution of writing systems follows a single developmental pattern. At every advance, the number of symbols in the script decreases and, as a direct consequence, the abstractness of the relationship between script and speech increases. This pattern of development seems to parallel the general trend of cognitive development in children. Results from two independent lines of research are of particular interest. First, anthropological studies (Laboratory of Comparative Human Cognition, 1979) have shown that children's conceptualization of the printed arrays in a text proceeds from pictures to ideas, to syllables, and finally, to "wordness." Second, according to E. Gibson (1977), one of the major trends in children's perceptual development is the increasing specificity of correspondence between what is perceived and the information in stimulation, as a beginning reader progresses from the whole to the differentiation of the whole, and then to the synthesis of the parts to a more meaningful whole. In a sense, the ontogeny of cognitive behavior seems to recapitulate the evolutionary history of orthographies. Certainly, this cannot be simply a biological coincidence (Gleitman & Rozin, 1977). Such parallelism implicates the importance of a match between the cognitive ability of the reader and the task demand imposed by the specific orthographic structure of the scripts. One is almost tempted to suggest that orthographic structure in a writing system must somehow mold the cognitive processes of its readers. In fact, it has been claimed that the processes involved in extracting meaning from a printed array depend to some degree on how the information is represented graphically (Besner & Coltheart, 1979; Brooks, 1977; Tzeng & Hung, in press). It is therefore conceivable that different cognitive strategies are required to achieve reading efficiency in various writing systems. One particular concern is whether these different cognitive requirements imposed by various script-speech relations impose a permanent constraint on our visual information processing strategies, such that readers of different scripts learn to organize the visual world in radically different ways. Evidence for such a new "linguistic relativity" hypothesis can be found in papers discussing the "weak" version of the so-called Whorfian hypothesis (Tzeng & Hung, in press) and in recent ethnographic studies on the behavioral consequences of becoming literate in various types of Vai writing systems (Scribner & Cole, 1978). Cross-language and cross-writing system comparisons are certainly needed to help us answer this and other questions.

Orthographic Variations and Cognitive Processes

We have reviewed the general background for the development of various types of written scripts. We have also briefly discussed the linguistic status of each of the three major types of orthographies in terms of its embedded script-speech relationship. Let us now turn our attention to the behavioral consequences of these variations. There are many issues which have recently been tackled by cognitive psychologists, anthropologists, and by neurolinguists. Among them, our concern will focus on those having to do with bilingual literacy.

1. Reading Disability

While the problem of reading disability is pervasive in languages adopting the alphabetic principle (e.g., English, German, Spanish, etc.), the rarity of reading disability at the beginning level has been noted in languages adopting syllabic and logographic systems (Makita, 1968; Tzeng & Hung, 1980). Makita attributes the success of Japanese initial reading instruction to the fact that Kana scripts have one-to-one grapheme-sound correspondence. Sakamoto and Makita (1973) further show that many Japanese children learn Kana symbols without formal instruction before they enter school. On the other hand, Tzeng and Hung attempt to account for the success of Chinese instruction in terms of linguistic considerations. They point out that Chinese, as a logographic script, is meant to express a single particular morpheme while ignoring many grammatical marking element (e.g., I WANT GO instead of I WANTED TO GO). That is, the character remains the same regardless of syntactical changes. In Chinese, the character-speech mapping is morphosyllabic in nature. Thus, for Chinese children the task of learning to read means simply to learn to associate each spoken syllable with a particular character of a designated meaning. In general, the orientation and the number of strokes which form the basis of a character bear no relationship to the sound of the spoken word. Even though the majority of modern Chinese characters are phonograms (Wang, in press), the success rate of using a base character to sound out another character is estimated to be low (less than 39% according to a recent analysis of Zhou, 1978). This lack of symbol-to-sound correspondence leaves the beginning readers a most straightforward way (and probably the only way) to master thousands of distinctive characters, namely, the way of rote memorization. This situation is very different from that of learning an alphabetic script where one has to be able to extract orthographic regularities embedded in written words in order to figure out the letter-sound correspondence rules. Therefore, beginning readers of Chinese (when the number of characters to be memorized is still limited) face a more concrete learning situation than those who are learning the alphabetic writing system. The ease of acquisition of the logographic system is further attested by a widely cited study in Philadelphia in which a group of second-grade school children with serious reading problems that had resisted even after extensive tutoring by conventional methods were able to make rapid progress in learning and reading materials written in Chinese characters (Rozin, Poritsky, & Sotsky, 1971).

While the evidence seems to be impressive, one has to be cautious in interpreting results reported in the above studies. The study reported by Makita (1968) and the one cited in Tzeng and Hung (1980) were both crude survey reports. Questionnaires were sent to school teachers and pre-designated questions were framed in a manner far from satisfactory. Moreover, in both Japan and Taiwan where literacy is highly valued and a great deal of social pressure is always imposed upon schools to make the schools look good, a simple survey on reading disability can never tell the whole story. For one thing, Makita claimed that Kana is easy to learn because it maps onto the sound at the level of syllable. However, linguistic analysis shows that Kana in fact maps onto the sound at the level of mora (Wang, in press), a smaller but more abstract unit than the syllable. And there is a report that Japanese children do have problems dealing with mora (Sakamoto, 1980). Furthermore, different countries have different criteria for reading disability. Thus, such evidence as provided by Makita and by Tzeng and Hung, without appropriate cross-cultural control, cannot be interpreted too enthusiastically. Rozin et al.'s (1971) data is interesting but methodological weaknesses make it less impressive than at its first appearance. Other criticisms have been advanced in Tzeng et al. (1977). It is important to get one thing straight: Learning a limited number of Chinese characters does not qualify a person as a successful learner of Chinese. The essential difficulty of learning Chinese scripts lies in its huge number of distinctive characters. Rozin et al.'s success in teaching second-grade non-readers in English to read "first" grade or lower materials in Chinese is hardly surprising.

I think it is fair to say that no hard evidence so far has been provided to support the rarity of reading disability in a certain type of orthography as compared to other types of orthographies. However, at different stages of acquisition, learning seems to be impeded by different kinds of difficulties. This is not surprising. Readers of a logographic script must face the problem of memorizing a vast amount of distinctive characters. Readers of a syllabary must search for invariances at one level while readers of an alphabetic system still another level. The commonality is that learning to read effectively is dictated by the special script-speech relationship embedded in a particular orthography. It is no wonder that the linguistic awareness of one's own language becomes a prerequisite condition of successful learning in the beginning readers. This is especially true in the alphabetic scripts with deep phonology (such as English, see Liberman, Liberman, Mattingly, & Shankweiler, 1980; Mattingly, 1979).

2. Neuropsychological Difference.

We know that in Japanese three different types of scripts (four if you consider the prevalent use of romaji) are used to represent text. So, a fluent reader of Japanese has to know all three types of scripts, namely, Kanji, Kitakana and Hiragana). Sasanuma and her associates (for a more detailed review of Sasanuma's work, see Hung & Tzeng, in press) have presented evidence showing that the ability of Japanese aphasic patients to use Kanji and Kana scripts may be selectively related to the specific type of aphasic disorder. Careful examination of the patients' performance suggested that impairment of Kana processing typically occurred in the context of the overall syndrome known as Broca's aphasia, while impairment of Kanji was characteristic of Gogi (word meaning) aphasia. The implication is that phonetic-based scripts such as Kana and logographic-based script such as Kanji require different brain location in their visual information processing. But this structural interpretation may not be necessary. Empirical research with Chinese characters by Tzeng et al. (1977) and the on-going research into the relationship between reading and speech by the Haskins group (Liberman et al., 1977) point to the importance of the auditory short-term store as necessary to primary linguistic activity such as comprehension and that morphological information may require phonetic storage at an intermediate stage of processing. The results reported by Sasanuma and her associates may be interpreted not as independent neural processing of the phonetic and morphemic components, but as differential realization of two levels of linguistic awareness (Erickson, Mattingly, & Turvey, 1977). Although clinical evidence such as the above case has its limit in generalizability, the observation of selective impairment in reading Kanji and Kana scripts among the Japanese aphasic patient nevertheless demonstrates differential task demands imposed by these two scripts.

Sasanuma's (1974) findings quickly prompted another series of research which is concerned with whether the visual lateralization effect (i.e., hemispheric dominance) would show differential patterns, depending on whether phonetic scripts (e.g., Japanese Kana, English alphabet, etc.) or logographic scripts (e.g., Chinese logographic and Arabic numerals) are employed as stimuli. The term "lateralization" refers to the different functions of the left or right cerebral hemispheres. Mishkin and Forgays (1952) tachistoscopically exposed English words to either the right-visual-field (RVF) or left-visual-field and found a differential accuracy of recognition, favoring words presented to the RVF, suggesting a left hemisphere superiority effect. On the other hand, research investigating whether the asymmetric visual field effects are subject to the influence of variations in the orthographic structure generally reports a different pattern. For instance, processing Yiddish words has been found to show a left visual field advantage and the habit of visual scanning during reading was suggested to assume an important role in the visual half-field experiment. The unique styles of Kanji and Kana symbols provide a testing ground for theories of cerebral organization. Hirata and Osaka (1967) and Hatta (1976) both found a suprior performance of the left hemisphere in the processing of Kana symbols. This result is similar to those obtained with alphabetic writing. Recently, Hatta (1977) reported an experiment measuring recognition accuracy of Kanji characters and found a LVF (right hemisphere) superiority for both high and low familiar Kanji characters. Also using a recognition procedure, Sasanuma, Itoh, Mori, and Kobayashi (1977) presented Kana and Kanji words to normal subjects and found a significant LVF superiority for the recognition of Kana words but a nonsignificant trend of LVF superiority for Kanji characters. Thus, it seems that for those sound-based symbols such as English words and Japanese Kana scripts, a RVF-LH superiority effect is to be expected in a tachistoscopic recognition task while a LVF-RH superiority effect is to be expected for the recognition of Kanji logographs. Controversy arises immediately concerning the reliability of the Kanji effect. Previous experiments conducted by Kersner and Jeng (1972) as well as by Hardyck, Tzeng, and Wang (1977) with Chinese subjects reported significant RVF superiority effect in the processing of Chinese characters. Thus, the cerebral orthography-specific localization hypothesis proposed by Hatta (1977) is questionable. A recent study by Tzeng et al. (1979) shed light on this issue. They found that, in fact, the LVF superiority was only obtained with recognition of single characters; a RVF advantage similar to that obtained with alphabetic materials, was observed when two or more characters which make up a linguistic term were used. Tzeng et al. interpreted these differential visual lateralization effects as reflecting the function-specific property of the two hemispheres and rejected the orthography-specific localization hypothesis. This interpretation was further supported by Elman's (personal communication) results that even with single characters, only the simple naming task showed a LVF right hemisphere dominance; a more complicated grammatical classification task showed a left hemisphere dominance. Therefore, the evidence for differential brain functions in processing phonetic-based and logographic scripts does seem to be strong so far as these functions are interpreted with respect to differential demands imposed by the scripts.

So far, I have briefly reviewed research on effects of orthographic variations on cerebral lateralization using two different approaches, namely, the brain lesion approach and the visual half-field experimental approach. It is true that differences were found in the clinical and experimental studies resulting from reading different orthographies. One may want to interpret these data as supporting the hypothesis of hemispheric specificity. However, Hung and Tzeng (in press) offers an alternative interpretation in terms of differential knowledge structures. According to them, the two different pattern-analyzing skills (i.e., recognizing kanji vs. kana scripts) may be viewed as reflecting two different types of acquired knowledge, namely, knowing that versus knowing how. The former represents information that is data-based or declarative, whereas the latter represents information that is based on rules or procedures (Kolers, 1979). According to Mattingly (1972), operations with these two types of knowledge require two different levels of "linguistic awareness." Whereas the realization of knowledge that requires only a primary linguistic activity (or Level I ability in terms of Jensen's (1973) classification), the realization of knowing how requires a more abstract secondary linguistic activity (or Jensen's Level II ability). The imbalance between kanji and kana impairments observed in Japanese aphasics (Sasanuma, 1974) may be the result of differential difficulties related to the performance of these two levels of linguistic activities. The dissociation of knowing how from knowing that has recently been demonstrated in amnesic patients (Cohen & Squire, 1980).

Due to their unique formation, Chinese characters offer extremely important opportunity for investigators to examine the different properties of the two hemispheres. However, it is essential that the investigation must start by analyzing the linguistic property of the characters. A recent study by Nguy, Allard and Bryden (1980) "demonstrated" that Chinese "pictorial" characters show a different pattern of lateralization effect in visual half-field experiments as compared to non-pictorial characters. But careful examination of their materials and their unconventional classification show only that their data are totally useless. For example, how can the character for "ghost" be pictorial unless they are seeing ghost? We have to avoid such irresponsible experiment.

3. Differential Processing Mechanisms and the Behavior Consequences.

One research issue concerns with whether different processing mechanisms are activated in reading different scripts and what would be the behavioral consequence, if any, of being literate in various writing systems. With respect to the first question, Besner and Coltheart (1979) have provided positive answers by showing that making quantity comparisons between two numbers may engage different processing mechanisms depending upon whether these numbers are presented in Arabic (logographic symbols) or in spelled-out English letters. Their data showed that comparing two Arabic numbers was subject to the interference of size incongruency whereas comparing two spelled-out numbers was not. Similar size incongruence interference occurs in a comparative judgment task (Paivio, 1975) when the two to-be-compared items are presented in picture form but not in spelled-out words. The conclusion from these results is that different lexical retrieval routes are activated in order to perform the comparative jugment task (Paivio, 1975). Thus, depending upon how meanings are represented in print, a reader may have to develop different processing strategies in order to achieve reading proficiency.

To tap into these different processing mechanisms, Turnage and McGinnies (1973) asked Chinese and American college students to study a 15-word list in a serial learning paradigm. They also manipulated the input modality of the stimulus presentation. It was found that Chinese students learned the character-list faster when it was presented visually whereas American students learned the word-list faster when it was presented auditorily. The finding on the Chinese characters is opposite to the famous modality effect (Crowder, 1978) in which auditory presentation of English words results in better recall than does visual presentation. The interpretation offered by Turnage and McGinnies (1973) is that Chinese logographs contain more characters with similar sounds but different meanings than is the case for English, and this characteristic of the orthographic structure may favor learning through the visual mode.

Turnage and McGinnies' (1973) study involved two different language populations. Not only were the scripts different, there was also a difference in spoken language. The script may not be the determinant factor; rather, the visual modality advantage could have been a result of differences in spoken languages. But this latter account was soon ruled out by a study comparing the learning rate of Korean words written in either Chinese characters or Korean Hangul (an alphabetic script, see Wang, in press). Koreans can transcribe their spoken language in either script. Park and Arbuckle (1977) examined the memory of Korean subjects for words written in these two types of writing systems and found that words presented in logographic script were remembered better than words presented in alphabetic script on recognition and free recall but not on paired-associate recall or serial anticipation. Thus, there is indeed an intrinsic difference with respect to the processing mechanism for these two scripts, and these differences seem not to be associative in nature.

But so far the most impressive line of research has been provided by Scribner and Cole (1978) in their ethnographic study of the cognitive conseqences for tribal Vai adults of becoming literate in Vai or Arabic. An analysis of the process of reading the Vai syllabary indicated that special task demands are imposed by the script. Vai is a tone language but tonal information is not marked in the script. Furthermore, no word boundaries or punctuation are indicated in writing a text so that the reader must group the syllables together to form words, then again integrate these into meaningful linguistic units. On the other hand, the Arabic script is an alphabetic system and is learned mainly through a rote memory process (the students don't understand or speak Arabic). When students of these two rather different scripts were tested in various cognitive tasks, Vai and Arabic literates did not differ in their ability to comprehend the word strings, but Vai literates were superior on the picture reading and syllable integration tasks which mimicked their normal reading activities. In contrast, Arabic literates performed better than Vai literates on the incremental memory task which presented task demands most similar to their every reading activities. These results indicate not only that different scripts impose different task requirements for achieving proficiency, but also that strategies developed to meet these requirements are transferable to situations with similar task requirements. Therefore, Scribner and Cole (1978) provide rather strong evidence for our hypothesis that becoming literate in certain scripts can have a long lasting effect in molding our information processing system.

4. Speech Recoding in Reading.

When people read to themselves, do they recode the visual input into some sort of speech-like code (i.e., articulatory, acoustic, or both)? The existence of such recoding is no longer in doubt (Baron & Treiman, 1980; Tzeng & Hung, 1980). The question now facing us is why. What factors encourage its use and what factors discourage it? Orthographies vary considerably in the demands on the reader. According to Liberman, et al. (1980), one of the aspects of such variations is the depth of the orthography, which can be defined as the relative distance between an orthography and its phonetic representation. For example, compared with Vietnamese, English is a rather deep orthography, and thus demands greater phonological development on the reader's part. It is quite possible that differences in orthographies along this dimension affect the use of speech recoding in silent reading. If the written forms on the page stand in a regular relationship to the sounds of language, the reader may use the grapheme-sound rules to help him derive the meanings of words. Such a path would be largely unavailable to the reader of Chinese, but would be highly available to English readers. Therefore, we would expect readers of English to engage in speech recoding more than would Chinese readers. Such an expectation was recently verified in a study conducted by Treiman, Baron, and Luk (in press).

The investigation into the relationship between the degree of speech recoding and the depth of orthography is an important one. By finding differences among orthographies along the dimension of grapheme-sound regularity, we can convince ourselves of the existence of some speech recoding in at least one of the orthographies studied. For example, Treiman, Baron, and

Luk's (in press) finding that more speech recoding occurs in alphabetic than logographic scripts (as indexed by longer reaction times and/or more mistakes in judging homophone sentences) enables us to conclude that some speech recoding does occur in reading alphabetic scripts. Once this fact is established, we can begin to provide accounts of the possible pathways (causal links among mental representations) between representations of print, speech, and meaning. For researchers who attempt to build cognitive models in terms of reading behavior, knowing the effect of the orthographic structure on the relations of these pathways should be one of their ultimate goals. So far, we know that whether or not a certain path will be bypassed or activated depends on the orthographic structure of the script one is reading. But the precise relationships are still far from clear.

One can push the argument even further and make the claim that, in an alphabetic script where the prediction of sound from letters alone is always valid (i.e., a perfect spelling-to-sound regularity), readers may automatically activate the phonological route to the lexicon. Experiments with a "phonologically shallow" orthography such as Serbo-Croatian (the major language of Yugoslavia which can be written in either Roman or Cyrillic) have consistently demonstrated that lexical decision proceeds with reference to the phonology (Lukatela, Popadic, Ognjenovic, & Turvey, 1980). Most importantly, these investigators found that even when matters were arranged so as to make the use of a phonological code punitive in accessing the lexicon, readers of Serbo-Croatian were unable to suppress the phonological code. This result is directly opposite to that obtained in English. Davelaar, Coltheart, Besner, and Jonasson (1978) found that under similar arrangements, readers of English abandoned the phonological route and opted for direct visual access to the lexicon. Thus, in a less shallow orthography such as English, reading may proceed simultaneously at several levels of linguistic analysis. The concept of depth with respect to the orthographic structure seems to be a useful construct in evaluating the issue of speech recoding. Here is an area in which comparative reading studies across different orthographies can yield important information.

Why do experimental psychologists so worry about the issue of speech recoding? Besides the pure intellectual pursuit, there are reasons of practical importance. For one, it relates to the choice of teaching method. There are currently two popular methods of teaching a six-year old child how to read. On the one hand, there is the phonics method which emphasizes learning the sound made by letters first, then learning to blend these sounds so that the written symbols make contact with their meanings through the spoken language. On the other hand, there is the whole-word method which emphasizes learning a direct connection between the written word (as a visual pattern) and the meaning for which it stands. Thus, depending on his/her attitude about the presence or absence of speech recoding during reading, the teacher decides whether the phonics or the whole-word method is a more appropriate one for teaching young children how to read.

The second practical reason for our concern about the issue of speech recoding is that of dialect-mismatch between teachers and a bilingual child (or for that matter the inner-city school children in this country). It is a common observation that in many bilingual classes, the spoken language of teachers contrasts sharply with that of the students. The consequence of such a mismatch can be a serious one (Chu-Chang, 1979) for learning to read. What should the teacher do? Only by examining the issue of speech recoding in reading will we be able to come up with some suggestions. For now, it is important that we call people's attention to this issue (Chu-Chang, 1979).

5. Bilingual Processing.

Our final issue concerns research in bilingual processing. In the past, bilingual studies have always dealt with spoken languages. There has been little concern with the possibility that experimental results may be contaminated to various degrees by variations in the orthographic structure. Recently, Biederman and Tsao (1979) reported a study in which they found that a greater interference effect was observed for Chinese subjects engaging in a Chinese-version Stroop-color naming task than for American subjects in an English-version. They attributed this difference to the possibility that there may be fundamental differences in the perceptual demands of reading Chinese and English.

Prompted by the intriguing finding of Biederman and Tsao (1979), Fang, Tzeng, and Alva (in press) went one step further and ran a modified version of the Stroop experiment. They asked Chinese-English bilingual subjects to name colors in either Chinese or English on either a Chinese version or an English version of the Stroop test. They found a reduction of the interference effect in the inter-language condition (i.e., responding in Chinese on the English version or vice versa) as compared with that in the intra-language condition. A similar experiment was performed using Spanish-English bilinguals with either English version or Spanish version Stroop test. Again the reduction of the Stroop interference was observed in the inter-language condition as compared to the intra-language condition. A further analysis reveals that although both experiments showed a reduction of interference in the inter-language condition, the magnitude of reduction was greater in the Chinese-English experiment than in the Spanish-English experiment. Since Spanish and English are both alphabetic scripts, switcing languages does not change the processing demands. However, since English and Chinese represent two different orthographic structures, switching from one to the other may prevent subjects from employing the same processing mechanism and consequently cause him to be released from the Stroop effect.

Fang et al. (in press) also made an interesting observation. They recalculated from Dyer's (1972) and Preston and Lambert's (1969) bilingual data the magnitude of reduction of the Stroop interference from the intra- to the inter-language condition. All together, there were six types of bilingual subjects, namely, Chinese-English bilinguals, Japanese-English bilinguals, French-English bilinguals, German-English bilinguals, Hungarian-English bilinguals, and Spanish-English bilinguals. Fang et al. ranked these bilingual data according to the magnitude of reduction from intra- to inter-language condition. The result is as follows: Chinese-English, Japanese-English (with Kanji), Japanese-English (with Kana), Hungarian-English, Spanish-English, German-English, and French-English. This ordering suggests that the magnitude of reduction (from intra- to inter-language) depends on the degree of similarity between the orthographic structures of the two tested languages. Thus, bilingual processing is definitely affected by the orthographic factor, and (it is fair to say that) the curious neglect of the orthographic factor in previous bilingual research is an unfortunate mistake. How can we resolve the independent versus inter-dependent lexica issue without taking into account variations in the orthographic structure?

From the viewpoint of cross-language research, the demonstration of the importance of the orthographic factor raises a host of more intricate questions to be answered. Do these differences result in different types of dyslexia? Do they necessitate different instructional strategies for teaching different scripts to beginning readers? To readers learning a second language which has a different orthographic structure?

Conclusion

There is an inseparable relationship between written language and spoken languages--they both are essential communication tools in human societies and to some extent the former is parasitic on the latter. There are many writing systems for many different languages. Essentially, they can be categorized into three basic writing systems based upon their various grapheme-meaning relationships: logographic, syllabic and alphabetic writing systems. The present paper has reviewed most of the empirical work which is relevant to the issue of bilingual literacy. I have tried to characterize differences of cognitive processes in reading different types of orthographies. I think the recognition that different orthographic structures impose different task demands is an important one. Without such recognition and an attempt to control the orthographic factor, cross-language comparisons of literacy skills are meaningless.

In the past, research in bilingual education and bilingualism has made an implicit but incorrect assumption that all bilinguals, regardless of the type of orthography in the original languages, are alike. Researchs reviewed above have shown that reading skills acquired in one orthography may not be the same as those acquired in another orthography, if these two orthographies have different script-speech mapping rules. Thus, instructional programs for bilingual children whose home language has a non-alphabetic orthography should be carefully designed in order to facilitate positive transfer and minimize negative interference due to the orthographic factor.

Comparative reading research across different languages is an important mission for it will help us to "unravel the tangled story of the most remarkable specific performance that civilization has learned in all its history" (Huey, 1908, 1968, p. 6).

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Chapter Three

A Chronometric Study of Sentence Processing in Deaf Children

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Abstract

It has been consistently reported that deaf children have tremendous problems in reading English sentences. Three experiments were conducted in the present study to investigate the nature of deaf children's reading inability. The first experiment looked into the letter-decoding process. It was found that deaf subjects took longer than normal hearing subjects in encoding and decoding alphabetic letters. The second experiment employed a sentence-picture verification paradigm. The results showed that deaf subjects adopted a visual-imagery coding strategy rather than a general linguistic coding strategy as described by Clark and Chase (1972) and by Carpenter and Just (1975). However, when the sentence was presented in manual signs (Experiment 3), deaf subjects' verification time showed that they adopted a general linguistic coding strategy. Thus, deaf subjects are capable of linguistic coding strategy, but they do not apply it to process printed English sentences. A second-language hypothesis was advanced to account for the obtained data. Deaf children's reading inability was also discussed from this perspective.

Introduction

The ability to manipulate and comprehend both spoken language and written language is critical for communication. It is unfortunate that the deaf are deprived of one and deficient in the other, with the result that the average reading ability of deaf children is far below that of normal children. The purpose of the present study is to identify sources of reading difficulty in deaf children, using an information processing approach.

Myklebust (1960) reported that on the Columbia Vocabulary Test, the mean score for normal children of age 9 is 20, while for the deaf the mean is 3. At age 11 the respective scores are 33 and 6; at age 13, the scores are 43 and 10; and at age 15, the respective mean scores become 63 and 11. Not only is the difference huge, but it also increases with age. Furth (1966) also reported that by age 16, only 12% of deaf students read at or above the 5th grade level, a level which is generally referred to as the "functionally useful reading level." Bornstein and Roy (1973), after summarizing results obtained from several different reading tests, found that 16-year old deaf students' reading ability is equivalent to a grade level of 4.66. Even at Gallaudet College, which was specially established for educationally successful deaf students, the reading ability is only equivalent to 9th or 10th grade (Reynolds, 1975). Not only do deaf children definitely lag behind hearing children at beginning reading stages but the gap also increases with each additional year of schooling. Moreover, the deficit seems to permeate the whole spectrum of linguistic ability. For many years, researchers have been trying to uncover the causes of these reading difficulties. Many different reasons have been suggested.

The first apparent aspect of reading which is missing from deaf children's reading behavior is their inability to transform the visual information into phonetic codes. The importance of phonetic recoding in reading cannot be overemphasized. Experimental results have shown that hearing persons tend to store visually acquired linguistic material in a phonetic form (Conrad, 1964; Kintsch & Buschke, 1969). Tzeng, Hung, and Wang (1977) demonstrated a similar phonetic recoding process when Chinese subjects were reading Chinese characters which do not have letter-sound correspondence rules. Further, Murray (1967) has reported experimental evidence showing that under certain conditions subjects still use a phonetic code even when such a code is not very effective.

Two different but not mutually exclusive suggestions have been proposed to explain the role of phonetic recoding in reading comprehension. The first is that the phonetic code is a more durable code than the visual code and thus is more effective in holding words within working memory until meaning can be derived or comprehension can be achieved (Baddeley, 1979; Baron, 1976; Huey, 1908; Kleiman, 1975; Liberman, Mattingly, & Turvey, 1972). The other suggestion is that phonetic recoding is required for mapping the written language onto the primary spoken language in order to make use of the processes and structures already developed for language comprehension (Liberman, Shankweiler, Liberman, Fowler & Fischer, 1977). Experimental results from comparisons of memory performance of good and poor beginning readers seem to be in agreement with both of these views.

If phonetic recoding plays such an important role in reading behavior, what happens to deaf children who, because of their specific handicap, do not have the phonetic code to prolong the information in working memory and thus cannot use it to help to map the written language into spoken language? To answer this and other related questions, Conrad and his associates conducted a long series of experiments with deaf children. In his recent book, Conrad (1979) reports a project in which he studied 468 hearing impaired students aged 15-16.5. Out of this population, 35% were profoundly deaf, having a hearing loss greater than 85 dB in the better ear. Only five of these people were found to be able to read at a level appropriate to their chronological age. All five of these good readers were very intelligent and, by Conrad's measure, were using internal speech for processing written material. Evidently, without some form of phonetic recoding, reading achievement cannot go very far.

Many investigators also believe that the reading deficiency of an deaf persons is the result of experience deficit in addition to the lack of speech recoding ability. Furth (1973) links the performance of deaf students to that of culturally deprived hearing students. A somewhat different view was proposed by Russell, Quigley, and Power (1976) and Moore (1978) who regard learning to read as being similar to learning a second language. The idea is that the code used by deaf persons in their everyday behavior is not deficient, but different in kind from the phonetic code used in spoken English. Since the orthographical regularity of written words is highly related to the phonological regularity of spoken words, deaf persons are forced to learn something they are not familiar with. The idea that differential coding schemes may be responsible for deaf children's reading difficulty is indeed a plausible one. It is true that most deaf children use gestural signs as their everyday communication medium, and Conrad (1979) has suggested that sign language may be an effective medium for thought. Although empirical studies of such a gestural code are just beginning, the idea of bilingual experience in deaf children's learning to read is an intriguing one and deserves more careful examination.

The present study is modeled on this approach, with the following basic assumption. For deaf children who acquire sign language as their first language, reading an array of printed material is artificial and requires a totally different set of information processing strategies. This assumption provides a rationale for the three experiments to be reported in the present paper. Since our concern is mainly with deaf children's learning to read English in America, the discussion will emphasize the contrast between English and American Sign Language (ASL).

ASL is, as compared to English, in every sense an independent, full-fledged language. ASL signs are not based on English words, and they may or may not have exact single-word English equivalents, just as a word in Russian or Chinese may or may not have an exact English equivalent. ASL signs also have their own rules of formation and a unique and complicated grammar for the production of correct signing sequences (Klima & Bellugi, 1978, 1979). Newport and Bellugi (1978) demonstrated that sign language has an hierarchical structure. That is, ASL, like English, has various levels of taxonomies for concrete objects.

Although many of the signs in ASL were derived originally from pantomime, over the years an increasing number of signs have lost the property of iconicity (defined as a natural system of icons and their denotations, a simple semiotic system in which signs and meaning closely match; see Stokoe, 1975). In fact, at first glance, the signs of modern ASL have become so arbitrary that someone not familiar with the language will not be able to understand what has been "said" by simply guessing from the shapes of the signs. Stokoe, Casterline, and Croneberg (1965) and Friedman (1977) have identified and categorized ASL signs according to four major dimensions: (a) hand configuration (shape of the hand in making the sign), (b) place of articulation (location of the hand on the body), (c) movement of the hand in making the sign, and (d) orientation of the hand in relation to the body. These dimensions are useful in studying the decoding process of deaf subjects' communicative behavior.

Many researchers have argued that ASL should be considered as an independent language because it shares many of the psychological properties of other human languages. For example, it has been observed that deaf people sometimes make "slip of the hand" mistakes just as normal hearing people sometimes make "slip of the tongue" mistakes (Bellugi & Klima, 1975). It has also been observed that deaf people take longer to generate "finger fumbler" sentences just as hearing people do for "tongue twister" sentences (Bellugi, Personal Communication).

If ASL should be considered as an independent language, then deaf people who use ASL should be considered as bilinguals when they are taught to read English. For deaf children with deaf parents (those children sometimes are referred to as the prelingual deaf) sign language should be considered as the native language and English as the second language. Even for deaf children who have hearing parents, sign language still is a predominant communication tool. Thus, learning to read English should also be considered as second language learning. Indeed, Drury (1980) has recently shown that the error patterns of deaf college students on the cloze task, in which words are randomly deleted from a prose pessage, are influenced only by the immediate environment of the deleted positions. This is exactly what is observed in a non-native English speaker when he/she is taking a cloze test (Alderson, 1979).

If reading English is a second language experience for deaf children, then the possibility that they employ two different coding strategies in processing signs and printed materials becomes an interesting empirical question. Although research in recent years has not yielded unambiguous results, most of it indicates that the decoding efficiency and consequently the speed of responding to verbal stimuli in the bilingual's second language is generally slower than in his or her firsts language, even after many years' use of the former. The semantic content of words tends to be decoded more slowly in the second language than in the first, even at very elementary levels: the process of decoding words belonging to a second language system simply requires more time (Dornic, 1979). The reason for this decoding deficit is not yet clear. It does seem clear, though, that somehow information processing in the second language is impaired, and that the deaf may share this common deficit in learning to read English. Since most bilingual research deals with spoken languages, a careful examination of deaf children's learning English as a second language will be important. For hearing children, learning to read a second language is usually accompanied by learning to speak that language. Hençe, they may still rely on phonetic codes. For deaf children, however, this is generally not the case and thus, they may develop differential coding strategies for processing signs and printed verbal materials. Let us review empirical research which investigates the coding strategies of deaf subjects in their processing of linguistic materials.

Frumkin and Anisfeld (1977) studied the three possible codes (i.e., orthographic, semantic, and manual) which may be used by deaf children in storing linguistic items. They found that deaf children were indeed using these three codes differentially to process linguistic materials under different input conditions. When the inputs were printed words, deaf children retained the orthographic shape and the semantic content, whereas when the units were signs, they retained the formational properties of signs and their semantic content. Their data also suggested that deaf children tended to rely on a semantic code while hearing children of the same age tended to rely on a phonetic code. For example, in a recognition test, hearing children tended to falsely recognize TOY (a distractor word) for BOY (a target word) while deaf children tended to falsely recognize GIRL for BOY. Frumkin and Anisfeld attributed this difference to the fact that deaf children do not have a speech code to effectively prolong the incoming information, so that they have to rely more on a semantic code. Conlin and Paivio (1975) also reported experimental evidence suggesting that deaf and hearing children were employing two qualitatively different strategies in processing verbal materials presented visually. Their data confirmed the observation of Odom, Blanton, and McIntyre (1970) that word signability (a measure of the ease with which a word can be represented as a gestural sign) is a critical variable in the verbal learning performance of the deaf. They concluded that gestural signs, visual features, and visual images all seemed to play major roles in deaf children's symbolization of verbal materials.

Bellugi, Klima, and Siple (1975) studied the nature of coding in deaf subjects' processing of ASL with short-term memory tasks. Their results indicated that deaf people were using structural and formational features of signs to retain sign information in short-term memory, just as hearing people use a phonetic code to retain linguistic information in short-term memory. Although this evidence suggests that deaf children can use gestural and motor-movement codes to retain information in short-term memoy, experimental results of studies on long-term memory in general show that the semantic code is used by both deaf and hearing subjects. Siple, Fischer, and Bellugi (1977) found that deaf subjects did not store the visual/gestural input in their original visual forms in long-term memory but rather in semantic categories just as normal hearing subjects would do with English words (Underwood & Freund, 1968). This result was replicated by Liben, Nowell and Posnansky (1978). They presented words and signs, which can be clustered either according to semantic categories or according to formational characteristics, and asked their subjects for free recall. Their results showed that deaf subjects do cluster the output by semantic category rather than by hand shape or other signing features.

So far most experimental results convincingly demonstrate that deaf people use a different set of multiple codes to process letters and words. It is still not clear what kind of representation they have after reading a sentence except to say that it must be semantic in nature. As is well known, reading a sentence involves much more complicated mental processes than merely identifying letters and words. Examining the coding process at the sentence level will undoubtedly yield important information about the reason behind deaf children's reading disability. Since deaf children seem to use two different strategioes in dealing with signs and with letters and words, it is highly probable that the final semantic representations will be different for sentences expressed in sign and for sentences expressed in English. With this hypothesis in mind, the present paper intends to investigate the reading behavior of deaf children at the level of sentence comprehension. This work will have both theoretical and practical implications. Theoretically, knowledge of cognitive processes in deaf people, because of their unique handicap, can shed light on many questions about the role of speech in cognitive development. Practically, uncovering the processing deficit underlying deaf childrens' reading difficulty will enable us to help the deaf to overcome their productional deficiency caused by the auditory impairment.

General Method

The aim of the present study is to provide information concerning the mental processes involved in sentence comprehension of deaf children. Since their reading achievement is general very poor, the experimental materials should not be so difficult as to interfere with comprehension. Similarly, the response chosen should not be so complicated as to interfere with easy execution. Thus, the following general paradigm was adopted: a stimulus array was presented for a brief period of time, followed by a judgment task in which the subject was asked to make a yes/no response according to a pre-specified criterion. The reaction time (RT) for making a correct decision was recorded and used as a dependent measure. Such a RT experimental paradigm has been popular in current information processing research. It has been successful employed to study many phenomena in cognitive psychology, including memory, perception, psycholinguistics, reading, etc. However, it has not been used in the deaf population to study problems beyond letter recognition.

Two experimental paradigms were employed in the present study. One is the letter decoding task originally developed by Posner, Boies, Eichelman and Taylor (1969). In this task, the subject is required to make a "same" or "different" judgment to simultaneously presented alphabetic letter-pairs. In the physical identity (PI) condition, the subject is instructed to respond SAME only if the two letters are exactly the same (e.g., AA, aa, etc.). In the name identity (NI) condition, letter-pairs are to be called SAME if they are identical to each other (e.g., AA) or if they share the same name (e.g., Aa). Posner and many others in different laboratories have consistently reported that it takes longer for subjects to make a name identity judgment than a physical identity judgment. This time difference has been interpreted to reflect the additional time required for determining the name associated with each character. This process which transforms the physical features into some meaningful unit is called the decoding process (Hunt, 1980). For normal hearing subjects, the name code is phonetic in nature. But for deaf students, the nature of the name code is less clear. In fact, we do not know whether Posner et al.'s letter decoding paradigm is applicable to deaf subjects. As mentioned above, deaf children may suffer from reading deficiency because of their lack of phonetic codes. It is desirable to employ the letter decoding paradigm with deaf children to see whether the speed of their decoding process also correlates with their other information processing operations.

The second paradigm used in the present study is the sentence-picture verification paradigm originally developed by Clark and Chase (1972). In this task, the subject reads a simple assertion about a picture, e.g., STAR IS ABOVE PLUS, then looks at the picture (e.g., $\overset{*}{+}$) and determines whether or not the assertion is an accurate description of the picture. In the above example, the subject's correct response should be "yes" and consequently this sentence is classified as a TRUE AFFIRMATIVE (TA) sentence. If the picture is "$\underset{*}{+}$", the correct response should be "no", and the sentence is classified as FALSE AFFIRMATIVE (FA) sentence. There are also negative sentences. For example, a target sentence may be STAR IS NOT ABOVE PLUS. If the picture shown is "$\overset{+}{*}$", then the subject's correct response should be "yes" and this is a TRUE NEGATIVE (TN) sentence. Similarly, if the picture shown is "$\overset{*}{+}$", the subject's correct response should be "no" and this sentence is clas sified as FALSE NEGATIVE (FN) sentence. The times required to read the sentence and to make the true-false judgment are recorded. The independent variable in such experiments is the linguistic complexity of the target sentences. The dependent variable is the reaction time for making a yes/no decision.

Results from this type of experiment are rather striking and maybe somewhat counterintuitive. The RTs for the four types of sentences form a linearly increasing function with the ordering TA<FA<FN<TN. In order to account for such an orderly linear increase, Carpenter and Just (1975) elaborated and modified Clark and Chase's (1972) original model and proposed a constituent comparison model. In this model, it is assumed that the sentence and picture are represented internally by logical propositional forms. After both representations have been formed, they are compared, component by component, from the innermost to the outermost constituent. It should be noted that for such a model to be successful, it is required that affirmative sentences are verified more rapidly than negative sentences, and YES responses (for TRUE sentences) are faster than NO responses (for FALSE sentences). Furthermore, the affirmative-negative effect should be considerably greater than the true-false effect. Later experiments (Hunt, Lunneberg, & Lewis, 1975; Just & Carpenter, 1975) seem to confirm these effects. However, the generality of the linguistic model was soon challenged by findings from subsequent studies.

MacLeod, Hunt, and Mathews (1978), in a large-scale study, gathered sentence verification data from 70 University of Washington students. Averaging over subjects, the constituent comparison model of Carpenter and Just (1975) accounted for 87% of the variance, which is of course an adequate replication of Carpenter and Just's report. However, a totally different picture emerged from further analysis of the individual data. While many subjects were reasonably well fit by the model, 16 out of 70 subjects provided data that showed quite a different pattern: The verification times were ordered TA<FA=FN>TN rather than the usual TA<FA<FN<TN. The data suggested that these 16 subjects were using some type of internal code other than the general linguistic code suggested by Carpenter and Just (1975). Examination of these 16 subjects' verbal and spatial aptitude scores revealed that all of them had relatively low verbal scores but considerably higher spatial scores. This result led MacLeod et al. to suggest that these subjects might use a visual-imagery code to process the linguistic information. That is, they might first translate the sentence into a visual image and then simply compare this newly formed visual image to the presented picture. Thus, at least two different coding strategies have been identified in performing the sentence-picture verification task, and the strategy choices themselves are predictable on the basis of subject characteristics.

Since profoundly deaf people do not usually have a speech code available, and are presumably using primarily a visual-spatial code, they were expected to perform like the visual-imagery subjects in the MacLeod et al. study. That is, for deaf subjects we should expect RTs for verification in TA, FA, FN, and TN sentences to form an ordering of TA<FA=FN>TN (as predicted by MacLeod et al.) rather than TA<FA<FN<TN (as predicted by Carpenter and Just). This hypothesis was tested in the second experiment of the present study.

Since we know from reviewing the literature that deaf people use different codes to process verbal and sign materials, it will be interesting to compare the results of sentence-picture verification under conditions of reading a printed sentence and perceiving actual signing. An additional question can be raised at this point. Which set of data, the sentence reading performance in Experiment 2 or the sign-perception performance in Experiment 3, would have a higher correlation with the letter decoding performance in Experiment 1? The answer will of course give us insight about the nature of the internal code formed during sentence comprehension by deaf subjects.

Experiment 1: Letter Decoding

There were two purposes for running this letter decoding experiment. First, this simple experiment served as familiarization and practice with the key pressing responses to be used in later more complicated experiments. Second, the data may reveal the nature of the name code for letters when there is little possibility of speech recoding. The obtained RTs in Experiment 1 are available for correlation with the RT data of Experiments 2 and 3. The degree and direction of these correlations will allow us to characterize the coding strategies used by deaf subjects.

Method

Subjects

Thirty-five profoundly deaf high school students at the California School for the Deaf in Riverside (CSDR) served as subjects. CSDR is a residential school for profoundly deaf and hard-of-hearing students. All classes, ranging from elementary to high school levels, are conducted in both sign and speech and ASL is extensively used on the campus. The age of the subjects ranged from 14 to 18, with a mean of 16.23. According to the school records, all of the subjects scored 90 and above on the Wechsler Intelligence Scale for Children (WISC) (IQ range from 90 to 133, with a mean of 109.62). All the subjects were deaf from birth. They all are classified as "profoundly deaf" with a hearing loss of 90 dB and above in the better ear.

Materials

The stimuli were the letters A, B, G, and H in upper and lower case. For each subject, each stimulus set contained 80 pairs of letters which were divided into two blocks of 40 pairs each. Within each block, the number of "same" and "different" responses to be made was equal. For each response category, there were equal numbers of upper-upper, upper-lower, lower-upper, and lower-lower case combinations. The order of items within each block was randomized separately for each subject.

Procedure

A list of letter pairs was presented pair by pair by a Kodak Carousal slide projector onto a screen in front of the subject. Two letters appeared on the screen simultaneously and remained on until the subject responded by pressing one of the two keys mounted on the table in front of him or her. One of the keys was labeled SAME while the other was labeled DIFFERENT. The subject was instructed to sit with the index finger of his right hand resting on the key on his right, and the index finger of his left hand resting on the key on his left. For half of the subjects, the instruction was to press the right key for making the SAME response and the left key for the DIFFERENT response. For the other half, the assignment was reversed. In short, a positional effect was ruled out by this balanced design.

A Hunter electronic digital timer was connected to the projector. As soon as a letter pair appeared on the screen, the timer was triggered and ran until the subject pressed one of the response keys. If the subject failed to respond within 5 seconds, a new trial began and the timer automatically reset to 0000. The experimenter recorded the times required for making a response.

The instructions for the physical identity condition were the following: "You are going to see a pair of letters on the screen. If you think that two letters are totally identical, for example, A A, or a a, please press the key labeled SAME. If you think the letters are not totally identical, for example, A a, or A B, please press the key that is labeled DIFFERENT. Please respond as quickly as you can but be accurate at the same time. There will be ten practice trials to help familiarize you with the procedure, and after that, we will start the experiment. Do you have any questions?"

The instructions for the name identity condition were very much the same: "You are going to see a pair of letters on the screen. If you think they refer to the same name, for example, A a, or a a, please press the key that is labeled SAME. If you think they refer to different names, for example, A B, or a b, please press the key which is labeled DIFFERENT. Please respond as quickly as you can but be accurate at the same time. Do you have any questions?"

Subjects were run individually and all the instructions were given in ASL.

Results and Discussion

All analyses were carried out on the mean RTs. Since the error rate was extremely low (less than 2%), errors were not included in the analysis. The results are summarized in Table 1, which shows a 2 (PI vs. NI) x 2 (SAME vs. DIFFERENT) matrix. The entries in the cells represent RTs, averaged across subjects, as a function of task and response mode. The data indicate that NI decisions took longer than PI decisions and DIFFERENT response took longer than SAME responses. An analysis of variance for a 2 x 2 factorial design with repeated measures confirmed the above observations by showing a significant main effect of decision types, $F(1,34) = 7.43$, $p < .025$, and a significant main effect of response type (i.e., SAME vs. DIFFERENT), $F(1,34) = 30.38$, $p < .01$. The interaction between the two factors was not significant, $F(1,34) = 3.09$, $p > .10$. In general, this pattern of results with deaf subjects is very similar to that obtained with normal hearing subjects by Posner et al. (1969) and Hunt, Lunneborg, and Lewis (1975).

Insert Table 1 about here

Following the arguments advanced by Posner et al. (1969) and Hunt et al. (1975), we may interpret the longer NI decision time as reflecting an additional operation of transforming a visual code into an abstract code. The results of the present experiment show that for deaf subjects this letter decoding process requires about 109 msec to accomplish, which is about 33 msec longer than the 76 msec obtained with the normal University of Washington students (Hunt et al., 1975), as depicted in Table 2. A glance at Table 2 reveals that the mean RT for PI decisions in deaf subjects is 688 msec while that for hearing subjects is only 533 msec: deaf subjects take 155 msec longer than hearing subjects to make a PI decision. Similarly, the mean RT for the NI condition is 797 msec for deaf subjects while for hearing subjects the corresponding time is 609 msec. Again, deaf subjects take 188 msec longer than hearing subjects to make a NI decision. Considering that deaf subjects have less experience in reading letters than college students, the slower encoding process observed in the former group is to be expected. Moreover, since transforming letters into an abstract code is an everyday experience for normal students but not for the deaf, there is also a reason to expect a slowing of the decoding mechanism in the latter group.

Insert Table 2 about here

In summary, the experimental results show (a) RT is a reliable measure for revealing mental operations in the deaf, (b) deaf subjects are generally slower than hearing subjects in both encoding and decoding processes. Hunt (1978), after reviewing many experimental results from different laboratories, found the decoding time (i.e., NI-PI) to be correlated with subjects' verbal ability. It would be interesting to see to what extent deaf subjects' letter decoding ability might correlate with their sentence comprehension ability. This relationship was examined in the following two experiments.

Experiment 2: Sentence Comprehension

The present experiment was concerned with deaf subjects' reading strategies when an array of printed English words was presented. sentence-picture verification paradigm (Clark & Chase, 1972) was employed since the experimental procedure is very simple and sophisticated models are available to account for the data. The task involved presenting a simple sentence followed by a picture whose content was or was not compatible with the meaning of the sentence. The subject's task was to verify the sentence by looking at the content of the picture. The dependent measure was the time required for the subject to make a correct verification decision. There were two independent variables. One was the truth value of the sentence, i.e., whether or not the picture depicted was described correctly by the sentence, and the subject made a YES/NO decision accordingly. The other was the syntactic structure of the sentence, i.e., whether the sentence was affirmative or negative. An orthogonal combination of these two factors produced four different types of sentences, namely, true affirmative, true negative, false affirmative, and false negative.

According to MacLeod et al. (1978), if the subject adopts a general linguistic coding strategy (i.e., a propositional code), the RT data should fit Carpenter and Just's (1975) constituent model. Otherwise, a visual-spatial coding strategy is implicated. Since our profoundly deaf subjects were generally poor in dealing with printed English sentences, we expected that their performance in the sentence-picture verification task would exhibit a visual-spatial coding strategy.

The sentence "STAR IS ABOVE PLUS" can also be expressed as "PLUS IS BELOW STAR". By presenting sentences in both ways we can examine the effect of linguistic markedness (Clark, 1974). It has been shown that the two modifiers "above" and "below" do not have equal linguistic status (Sapir, 1944). The former is neutral or unmarked while the latter is non-neutral or marked. This concept of linguistic markedness can be illustrated with the unmarked "tall" and the marked "short." When we ask someone "How tall is Tom?", we usually do not imply anything. However, when ask someone "How short is Tom?", we imply that Tom is short and we want to know how short. Clark and Chase (1972) demonstrated that subjects take longer to process sentences containing BELOW than sentences containing ABOVE. This effect of linguistic markedness is consistently found in the sentence-picture verification paradigm (Carpenter & Just, 1975; MacLeod, et al., 1978). If deaf subjects do not use a general linguistic coding strategy, however, we would expect no effect of linguistic markedness.

Method

Subjects

Twenty profoundly deaf high school students who served as subjects in the first experiment also participated in this experiment.

Materials

The stimuli were the eight sentence-picture pairs shown in Table 3, and another eight pairs in which only the "+" and "*" positions in the picture were reversed. Thus, altogether, there were 16 sentences in one block. Every subject was tested in 4 blocks of these 16 sentences and the order of sentence with each block was counterbalanced across subjects.

Insert Table 3 about here

Procedure

The sentence-picture pairs were presented by a Kodak Carousel slide projector onto a screen placed in front of the subject, who was instructed to read the sentence as long as he needed up to 5 seconds and to push a white button mounted on the table in front of him when he understood the meaning of the sentence. A digital timer was connected to the slide projector in such a way that it would start as soon as the sentence appeared on the screen. The timer ran until the subject pushed the white button. The time required for the subject to read the sentence was recorded by the experimenter as sentence comprehension time. A picture appeared on the screen immediately after the removal of the sentence. The subject had been instructed to then make a yes or no judgment according to the relation between the sentence and the picture. If the preceding sentence truly described the content of the picture, a yes response should be made. Otherwise, a no response should be made. The subject was instructed to indicate his or her decision by pressing one of the two telegraphic keys, mounted beside the white button, with the index finger of the writing hand. Half of the subjects were asked to press the key on the right hand side of the white button for the yes decision and the key on the left hand side of the white button for no decision. The other half were instructed to do just the opposite. The subject was instructed to make the verification decision as quickly as possible. The time required for the subject to make a correct decision was recorded as the sentence verification time. Feedback was given to the subject after each trial. The subject was told that if he or she made a correct response, a small light in front of him or her would be lit by the exerimenter. All instructions were given in ASL by an experimenter who was highly familiar with ASL. The subjects were run individually.

The detailed instruction for this experiment was: "You are going to see a sentence appearing on the screen. You can read the sentence as long as you need, for up to 5 seconds. When you understand the sentence and are ready for the picture, please press the white button in front of you. As soon as you press the button, the picture will appear. Your task is to make a judgment as to whether or not this sentence is a true description of the picture. If it is, please press the YES key; if it is not, please press the NO key. After you press the response key the picture will disappear, and the next sentence will appear in 5 seconds. If you make a correct response, the small light in front of you will go on as a feedback to you. Please respond as quickly as you can but be accurate at the same time. Do you have any questions?"

Results and Discussion

Before presenting the results of this experiment, one thing should be mentioned. When this experiment was initially planned, it was thought that a simple telegraphic sentence such as "STAR IS ABOVE PLUS" would be easily comprehended by our high school deaf students. It turned out that this was not the case at all. No subject was able to comprehend such sentences in less than five seconds. Reading English sentences is definitely a major problem for these students. Because of the long time needed to comprehend sentences, the sentence comprehension time was not a sensitive measure, and consequently it was decided not to analyze this measure. Therefore, only the results of verification RTs were analyzed; these results are summarized in Table 4.

An analysis of variance for a 2 (AFFIRMATIVE vs. NEGATIVE) x 2 (TRUE vs. FALSE) factorial design with repeated measures was performed on the raw verification RT data. It showed a significant main effect of syntactic structure, with the negative sentences requiring longer verification times than affirmative sentences $F(1,19) = 8.5$, $p <.01$. The main effect of truth value was also significant, with false sentences requiring longer verification times than true sentences, $F(1,19) = 14.97$, $p < .01$. There was also a significant interaction between the above two factors, $F(1,19) = 8.09$, $p < .01$. Careful examination of Table 4 reveals that this interaction is based mainly on the fact that the effect of syntactic structure was smaller for false sentences. Post-hoc analyses with Tukey's HSD procedure confirmed this observation by showing a significant simple effect of syntactic structure for the true sentences ($p < .01$) but a negligible effect for the false sentences ($p > .10$).

Insert Table 4 about here

The above pattern of interaction immediately calls into question the adequacy of Carpenter and Just's (1975) constituent model as an appropriate account for the data obtained in this experiment. According to the constituent model, the average amount of time required for each sentence type should vary from k units for a TA sentence to k+1 units for a FA sentence, to k+4 units for a FN sentence, and to k+5 units for a TN sentence. In order for such a linear increasing function to be held, the general trend of the RTs should at least exhibit the following relationships: TA<FA<FN<TN. Clearly, the strategy that deaf subjects adopted for such a sentence-picture verification task is not similar to the general linguistic coding strategy described in Carpenter and Just's model.

Carpenter and Just (1975, Table 4,5,7, & 8) reviewed a great number of studies and convincingly showed that the linear model effectively captured a very large percentage of the variance in reaction time across conditions. The present data were tested against their model by two stringent criteria.

The first test finds the best-fitting curve for the present data. Figure 1 shows the four verification RT means arrayed in the order predicted by the Carpenter and Just (1975) constituent comparison model. A trend analysis for linearity was performed and the statistical test suggested no trend for linearity, $F(1,57) = 0.467$, However, a further analysis revealed a significant quadratic trend, $F(1,57) = 4.75$, $p < .05$, suggesting that the data might fit better with MacLeod et al.'s (1978) visual-imagery model than with a general linguistic model.

Insert Figure 1 about here

The second test looks at the ratio of negation time to falsification time. According to Clark and Chase (1972), negation time (NT) refers to the extra time to process a negative. Specifically, NT = [(TN+FN) - (TA+FA)]/2. Similarly, falsification time (FT) is the extra time required if the core propositions mismatch, namely, FT = [(TN+FA)-(FN+TA)]/2. These concepts have been discussed fully in Catlin and Jones (1976) as well as in Shoben (1978) and it is unnecessary to describe the mathematical details here. Suffice it to say that for most studies reviewed by Carpenter and Just (1975) in which the sentence precedes the picture, the ratio of negation time to falsification time is about 4 (Catlin & Jones, 1976). Following the equations given above, the estimated NT and FT in the present experiment are 145.5 msec and 105.5 msec, respectively. The ratio of NT to FT is 1.379, nowhere close to the ratio obtained with normal hearing subjects.

These two tests enable us to reach the conclusion that deaf subjects indeed use a totally different strategy to perform the sentence-picture verification task. What is the nature of this strategy? The data give two different clues. First, the NT/FT ratio of 1.379 is closer to what has been obtained in the sentence-picture verification paradigm when the picture precedes the sentence, namely about 2 (Catlin & Jones, 1976; Shoben, 1978). Hence, a picture-coding strategy is implicated. Second, the inverted-U curve depicted in Figure 1 looks very similar to the pattern obtained by MacLeod et al. (1978) with those subjects whose RT data correlated highly with their spatial ability and less with their verbal ability. Again, a visual-spatial type of coding strategy is implicated. Thus, it seems reasonable to propose that deaf subjects perform the sentence-picture verification task in the following steps:

1. When the sentence is presented, they take all the time they need to form a visual image of it based upon the semantic clues of each word in the sentence;

2. They respond that the sentence has been comprehended when they can translate the verbal sentence into a visual image.

3. When the picture appears on the screen, they form a visual image of it;

4. They compare the two images and make a response.

This visual-spatial strategy (MacLeod et al., 1978) differs from the general linguistic model (Carpenter & Just, 1975; Clark & Chase, 1972) in two major respects. First, the process of translation from a verbal string into a visual image takes place as the sentence is comprehended rather than as the picture is verified. Thus, the major difficulty of the task is at the sentence comprehension stage. Second, as the comparison process is to be on visual images, the concept of negation becomes less important. One would expect to find that the true-false contrast in verification time should be stronger than the affirmative-negative contrast. This expectation is consistent with the observed interaction between these two factors, due to a reduced effect of syntactic structure in false sentences. This finding provides additional support for the conjecture that the factor of syntactic structure is not as important as the factor of the truth value. Taken together, the results of the present experiment suggest that deaf subjects adopt a visual-imagery coding strategy during sentence comprehension.

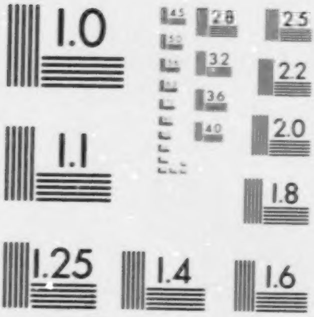
The observation that the data do not fit into a general linguistic model gains further support when the effect of linguistic markedness is examined. When the ABOVE sentences and BELOW sentences were analyzed separately, the average verification RTs were 1323 msec and 1296 msec, respectively. Statistical evaluation with a dependent t showed that the difference was not significant, t(19) = .74. In fact, the difference was in the wrong direction. This absence of a supposedly very robust linguistic effect reinforces the assertion that the deaf subjects did not use a general linguistic coding strategy in verifying the picture against the preceding sentence. Conceivably, one might find a linguistic marking effect during the first stage of sentence processing, which was not examined separately by the present study. What has been claimed here is that the resulting code cannot be linguistic in nature and that deaf subjects used this non-linguistic code to make their verification decision.

Finally, since subjects in this experiment also had participated in the letter-decoding experiment, the RTs of the present experiment (collapsed over sentence types) were correlated to the letter-decoding times (i.e., NI-PI) obtained in Experiment 1. The resulting correlation coefficient was a nonsignificant .13. Apparently, performance in the letter decoding task does not predict performance in reading sentences, even though each sentence is composed of many letters. Two different processes are implicated, and we will discuss these processes further after we examine the results of the next experiment.

Experiment 3: Comprehension of Signed Sentences

The results from the last experiment show that deaf subjects, unlike hearing subjects, do not use a linguistic code to verify a picture against a

PG



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

previously read English sentence. Instead, they seem to translate the printed sentence into a visual-imagery code and then make their verification decision based upon such code. There are at least two possible explanations. First, it is possible that the visual-imagery coding strategy is the general strategy that deaf subjects use to process external information, be it verbal or non-verbal. This explanation assumes that deaf subjects generally do not represent information in a linguistic or propositional format. Second, deaf subjects may not use a linguistic coding strategy in this task because of their inability to process English efficiently. This explanation assumes that deaf subjects are capable of a general inguistic coding strategy but because of their inefficiency in reading printed English prefer to adopt a visual-imagery coding strategy in the picture verification paradigm.

The key question differentiating the above two explanations is whether or not a linguistic coding strategy will be used by deaf subjects when the task is less demanding. The present experiment was conducted to answer this question. In this experiment, a modified sentence-picture paradigm was used. Instead of presenting the sentence in printed form, each sentence in this experiment was signed word by word by an ASL signer. Upon the completion of the signed sentence, the picture appeared on the screen. Since all the subjects were highly familiar with ASL signs, and the sentences were simple in structure, it was expected that such signed sentences would be easier for them to comprehend. This expectation was confirmed. It was found that subjects showed no difficulty in comprehending such sentences. The target sentences and the experimental manipulations in this experiment were the same as those of the last experiment. Comparisons of results obtained in these two experiments should yield important information about the coding strategies of deaf subjects under various conditions.

Method

Subjects

Fifteen profoundly deaf high school students who participated in Experiment 1 but not in Experiment 2 were recruited again to serve as subjects in the present experiment.

Materials and Procedure

The materials and procedure in this experiment were the same as in Experiment 2 except that the sentences were presented by an ASL signer signing the sentence word by word (i.e., each sign corresponding to each English word and order) to the subject. Again, the dependent measure was the sentence verification time.

Results and Discussion

In contrast to the last experiment where subjects showed great difficulty in reading printed English sentences, subjects in the present experiment comprehended the signed sentence with ease. Most subjects were ready to press the white button to signal the comprehension of the presented sentence almost as soon as the last word in the sentence was signed. The ease of sign perception supports the contention that signing is a natural and familiar communication tool for these subjects.

Results of verification RTs with respect to the two independent variable are summarized in Table 5. A 2 (Affirmative vs. Negative) x 2 (True vs. False) ANOVA similar to the one used in Experiment 2 was performed on the raw RT data. It revealed a significant main effect of Truth Value, $F(1,14) = 11.71$, $p < .01$, and a significant main effect of syntactic structure, $F(1,14) = 13.06$, $p < .01$. There was also a significant interaction between the above two factors, $F(1,14) = 6.47$, $p < .05$. In general, the pattern of results from the present experiment is similar to that of Experiment 2. However, a careful examination of Table 4 and 5 reveals the following differences:

Insert Table 5 about here

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1. Whereas Table 4 shows a greater effect of truth value than of syntactive structure, Table 5 shows a greater effect of syntactic structure than of truth value (263.5 msec vs. 109.5 msec).

2. Whereas the interaction effect of Table 4 is accounted for by the disappearance of a syntactic effect in false sentences, the interaction of Table 5 seems to result from the disappearance of a truth value effect in negative sentences. In fact, post-hoc analyses with Tukey's HSD procedure showed that the simple effect of negation was significant in both true and false sentences.

Taken together, the pattern suggests a very strong effect of sentence structure. This result alone points to the possibility of a linguistic code in comprehending ASL sentences. The data may be tested against a general linguistic model under the criteria set up in the last experiment. To begin with, the four verification RT means were plotted in Figure 2 in the order predicted by Carpenter and Just's (1975) constituent comparison model and a trend analysis was applied to search for a curve with the best goodness-of-fit. The results showed a very strong linear trend, $F(1,42) = 30$, $p < .01$, which accounted for 84% of the variance. The trend analysis also showed that departure from linearity was not statistically significant, $F(2,42) = 2.9$, $p > .10$. Thus, the results of the present experiment with signed sentences were consistent with a general linguistic model (Carpenter & Just, 1975; Catlin & Jones, 1976; Clark & Chase, 1972).

Insert Figure 2 about here

Next, the reduced effect of the true-false factor plus the enhanced effect of negation suggests a very different ratio of negation to falsification time as compared to that obtained in the last experiment. Following the equations described in Experiment 2, the negation time and the falsification time came out to be 263.5 msec and 79.5 msec, respectively. The resulting NT/FT ratio is 3.314, very close to the ratio of 4 predicted by a linguistic coding model (Carpenter & Just, 1975; Catlin & Jones, 1976; Shoben, 1978).

But what of the other linguistic effect, that of markedness? Table 6 displays the relevant data. As the figures in the second row indicate, the averaged verification RT is 1242 for the "above" sentences and 1317 for the "below" sentences. A dependent t test reveals that the difference is significant, $t(14) = 2.14$, $p<.05$. Again, this is consistent with a linguistic model.

Insert Table 6 about here

Putting all these pieces of evidence together, we can conclude that the code upon which subjects based their verification decisions in this experiment is linguistic in nature. It shows particular sensitivity to the syntactic factor as well as to the effect of linguistic markedness. Therefore, deaf subjects do have the linguistic coding strategy at their disposal, but they simply do not spontaneously apply it to a reading task. The absence of a linguistic coding strategy when sentences are presented in print suggests that deaf subjects may treat reading not as a linguistic activity but rather as a general problem-solving task. Hence, based upon the task demand (in this case, picture verification), they adopt a visual-imagery strategy which seems to meet the demand. The inverted U in Figure 1 and the low NT/FT ratio observed in Experiment 2 give strong evidence for a visual-imagery code (MacLeod, et al., 1978). Whether this explanation is correct remains to be tested in further studies.

Finally, the correlation between the verification RTs (collapsed over sentence types) in the present experiment and the letter-decoding RTs in the first experiment was also calculated. The resulting correlation coefficient is .52 which is significant at the .05 level with an n of only 15. This means that the mechanistic process involved in the letter decoding task shares some common property with the decoding of signs in the comprehension of signed sentences.

General Discussion

It has been consistently reported that deaf children have severe reading problems. The present study considered this problem from an information processing viewpoint. Using chronometric (RT) procedures, three experiments were conducted to examine various coding strategies that may be used by deaf subjects in different linguistic activities. The rationale behind these experiments is that, by discovering the similarities and differences in coding strategies between deaf and hearing subjects in various information processing tasks, we may be able to identify the basic reasons for deaf children's subjects do have the linguistic coding strategy at their disposal, but they simply do not spontaneously apply it to a reading task. The absence of a linguistic coding strategy when sentences are presented in print suggests that deaf subjects may treat reading not as a linguistic activity but rather as a general problem-solving task. Hence, based upon the task demand (in this case, picture verification), they adopt a visual-imagery strategy which seems to meet the demand. The inverted U in Figure 1 and the low NT/FT ratio observed in Experiment 2 give strong evidence for a visual-imagery code (MacLeod, et al., 1978). Whether this explanation is correct remains to be tested in further studies.

Finally, the correlation between the verification RTs (collapsed over sentence types) in the present experiment and the letter-decoding RTs in the first experiment was also calculated. The resulting correlation coefficient is .52 which is significant at the .05 level with an n of only 15. This means that the mechanistic process involved in the letter decoding task shares some common property with the decoding of signs in the comprehension of signed sentences.

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Finally, letter decoding times correlate significantly with verification times for signed sentences but not with verification times for printed sentences. Two independent processes are implicated for letter decoding and for reading in deaf subjects.

These results reveal a cogent point that should be a lesson to investigators of reading. Presenting a printed sentence to subjects and asking them to "read" it does not necessarily mean that the resulting code must be in linguistic in nature. The data suggest that under different presenting modes deaf subjects employ different coding strategies to process sentences. In fact, their reading behavior exhibits a pattern which is consistent with that of deaf subjects in other reading tasks reported in the literature. They tend to engage more in a means-end analysis which emphasizes the identification of words in the stimulus sentence (Liben, Nowell, & Posnansky, 1978; Quigley, Wilbur, Power, Montanelli, & Steinkamp, 1976; Siple, Fischer & Bellugi, 1977). This type of problem-solving strategy is best exemplified by the results of Experiment 2 where a pattern of verification RTs shows that subjects' sentence processing is guided by the subsequent picture, instead of vice versa. Such a problem-solving strategy requires conscious manipulation of information in active memory and appears to demand attention (Posner & Snyder, 1975). On the other hand, a highly overlearned decoding process such as sign preception appears to require relatively little attention. In Experiment 3, the sentence was expressed in ASL morphemes which were presumably highly familiar items; thus, word identification was automatic and attention could be diverted toward other aspects (e.g., the syntactic structure) of the sentence. This distinction between the two kinds of effect of linguistic markedness.

Finally, letter decoding times correlate significantly with verification times for signed sentences but not with verification times for printed sentences. Two independent processes are implicated for letter decoding and for reading in deaf subjects.

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When deaf subjects start to learn to read English, they are confronting a totally new set of linguistic rules. Not only is the language itself a different one, but also the alphabetic principle embedded in the printed array is a rather peculiar one. It has been shown that the grapheme-meaning relationship in English script is morphophonemic in nature and requires a high level of linguistic awareness for its mastery (Gleitman & Rozin, 1977). Even for a normal hearing child, such an abstract relationship is difficult to assimilate. But, in addition, deaf children do not have the phonological repertoire upon which English orthography is based. It is not difficult to appreciate deaf children's tremendous difficulty in learning to read English.

If we accept the conceptualization that learning to read English is a novel experience for deaf children, then it may be expected that many of their reading problems should parallel those of the bilingual with his less competent language. For example, as in the results of Experiment 1, a bilingual subject is usually slower in encoding and decoding his subordinate language. Dornic (1979), after reviewing most of the bilingual processing literature in a variety of language combinations such as Swedish-English, Swedish-German, French-English, Czech-German, Finnish-Swedish, English-German, etc., concludes that for some reason a bilingual subject is unable to apply the automatic encoding and decoding processes he has already developed for his dominant language to the reading of his less competent language. From the results of the present three experiments, it is clear that deaf subjects are unable to apply their existing linguistic coding strategies and their automatic decoding skills to comprehend a printed English sentence.

In conclusion, based upon results of the present three experiments and of other studies on deaf children's reading ability, it is clear that deaf children indeed have great difficulty in reading English. Several major learning difficulties can be identified.

First, the grapheme-meaning relationship that characterizes the English alphabetic script is morphophonemic in nature. It is difficult for deaf subjects, who are used to the morpheme-based representation of ASL signs, to grasp such a morphophonemic representation. Even a normal hearing child must be able to take advantage of the orthographic regularities in the printed arrays in order to become a good reader (Massaro, 1975). Gibson, Shurcliff, and Yonas (1970) have demonstrated that deaf children are also sensitive to the orthographic regularities of English words in their reading performance. Since deaf children do not have the phonological structure upon which the orthographic regularities are built, the question of how to help them to acquire the higher level of linguistic awareness toward the English script should be a challenge for further research. Current research on the relationship between meta-cognitive ability and reading performance (Flavell & Wellman, 1977) should yield important information to help us meet that challenge.

Second, lack of linguistic awareness toward English prevents deaf subjects from developing automaticity in letter decoding and word recognition.

In consequence, they do not apply their existing linguistic coding strategy to process English. Thus, it is not the eye which is not adapted to linguistic information; rather, it is a problem of dealing with a novel orthography without appropriate linguistic skills. Since deaf subjects do not process printed sentences in a linguistic code, they concentrate on lower-level processing such as word identification which demands a great deal of attention. Hence, little capacity is left for higher comprehension processes. Such a problem-solving strategy is also very much task dependent. Therefore, many of the inconsistent reports with respect to deaf subjects' reading strategies may be resolved by task analysis.

Finally and not unrelated to the last point, the concept of automaticity in reading implies a hierarchical system of semantic, syntactic, and perceptual controls. Within the system, the reader can move from one level to another. The purpose of instruction is then to practice at the lower levels until they function automatically. Thus, deaf children can use the method of repeated reading of a story to progress at each reading from (1) identifying printed words to (2) getting the meaning of the words to (3) comprehending the story. This method is simply to have deaf children do what some good readers did as beginners: read and reread the same story many times until they achieved automatic processing of words so that they could focus attention on comprehension. Alternatively, we can have deaf children read materials which are interesting but repetitious, particularly in vocabulary (Singer, 1976). According to Singer (1976), automatic recognition of words, particularly function words (conjunctions, and prepositions which tie together the content words such as nouns, adjectives, verbs, and adverbs), is most likely to develop from repeated reading, from reading series books, or from a large amount of reading of relatively easy books. Once the mechanistic processes of lower level processing become automatic, deaf children may be able to pay more attention to higher-level processing such as creating a coherent propositional base from a given text and making inferences beyond the information given.

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TABLE 1

Mean RTs (milliseconds) for NI and PI conditions across same-difference responses in Experiment 1

Response	PI Condition	NI Condition	Mean
Same	688	797	742
Difference	820	866	843
Mean	754	832	792

TABLE 2

Mean RTs in NI and PI conditions for deaf subjects in Experiment 1 as compared to mean RTs for normal hearing subjects in the same conditions@

Subjects	NI Condition	PI Condition	NI-PI
Deaf	797	688	109
Hearing	609	533	76
Net RT difference	188	155	33

@ Data for hearing subjects were collected by Hunt et al. (1975).

TABLE 3

The sentence-picture stimulus pairs as a function of trial type, hypothetical representation, and number of constituent comparisons

Trial Type	SENTENCE	PICTURE	SENTENCE REPRESENTATION	PICTURE REPRESENTATION	NUMBER OF CONSTITUENT COMPARISON
TA	STAR IS ABOVE PLUS PLUS IS BELOW STAR	* +	[AFF(STAR,TOP)]	(STAR,TOP)	K
FA	PLUS IS ABOVE STAR STAR IS BELOW PLUS	* +	[AFF(PLUS,TOP)]	(STAR,TOP)	K + 1
TN	PLUS IS NOT ABOVE STAR STAR IS NOT BELOW PLUS	* +	[NEG(AFF(PLUS,TOP))]	(STAR,TOP)	K + 5
FN	STAR IS NOT ABOVE PLUS PLUS IS NOT BELOW STAR	* +	[NEG(AFF(STAR,TOP))]	(STAR,TOP)	K + 4

TABLE 4

Mean verification RTs as a function of trial type for 20 subjects in Experiment 2

Response	Affirmative	Negative	Mean RT
True	1072	1323	1197
False	1395	1435	1414
Mean RT	1233	1379	1306

TABLE 5

Mean verification RTs as a function of trial type sentence for 15 subjects in Experiment 3

Response	Affirmative	Negative	Mean RT
True	1066.8	1409.6	1238.2
False	1255.467	1439.8	1347.63
Mean RT	1161.13	1424.7	1292.96

TABLE 6

Mean RTs for linguisticly marked proposition "BELOW" and unmarked proposition "ABOVE" acrossing two experimental manipulations@

	BELOW	ABOVE	DIFFERENCE
Printed sentence	1296	1323	-27
Signed sentence	1317	1242	+75*

@ In Experiment 2, the sentence is presented by printed English words. In Experiment 3, the same sentence is presented by ASL with each sign corresponding to each English word.

* $p < .05$

Chapter Four

A Critical Evaluation of the Horse-Racing Model of Skilled Reading

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Abstract

In the past, experiements with words presented in the format of mixing upper- and lower-case letters has been conducted to gather evidence for "visual reading" in skilled readers. We critically examined the conceptualization behind these experiments. Two new experiments were reported to show that less skilled readers in fact suffered more than good readers when the visual patterns of the presented words were distorted by mixing upper- and lower-case letters.

Since naming latency and the speed for making a lexical decision upon seeing a briefly presented word are highly correlated with reading comprehension scores (Adams, 1979; Frederiksen, 1978), it is natural that one of the major concerns in reading research has been the attempt to delineate differences between good and less skilled readers with respect to their ability to decode a printed word. It is expected that models of basic reading process should be able to account for the difference in the word recognition ability between good and less skilled readers.

Preoccupied with the concepts of speed and efficiency, many reading models of information processing postulate at least two different pathways linking the printed array and its lexical entry. One such pathway is phonological and requires a process of grapheme-phoneme conversion called speech recoding. The other pathway represents a "visual route", and implicit in the concept of the visual route is the notion that some sort of internal visual representation mediates between a word's printed form and its semantic representation (McCusker, Hillinger & Bias, 1981). It is further assumed that the visual and the phonological pathways in most cases proceed in parallel but that the former usually reaches the lexical entry much faster than the latter (Meyer, Schvaneveldt & Ruddy, 1974).

In recent years, such a dual access model of reading has gained more and more acceptance (McCusker et al., 1981). It is time to examine its ability of handling findings from experiments concerning word recognition. First, how does it explain the speed difference between good and less skilled readers? According to this model, the phonological pathway may be important for the less skilled readers, but the increases in reading speed by good readers might well reflect a "bypass" of phonological recoding in favor of visually mediated access. The reason is, "Specifically, with increased practice, the size of the pool of visually accessible lexical entries would increase, with a concomitant increase in reading speed." (McCusker et al., 1981, p. 235). Second, how does it account for the speed difference in the recognition of high and low frequency words? The model assumes the existence of a pool of high-frequency words that may be accessed rapidly via a visual representation; all other words, having no such visual representation, would by default be accessed by the slower phonological recoding procedure. On the surface, these accounts seem to handle the data beautifully and with compact logic. A moment's reflection, however, suggests otherwise.

As mentioned above, the idea of bypassing a phonological pathway has been entertained by many reading models, including the currently most popular dual-access model. Inherent in all these models is the assumption that some visual configuration information provides an alternative route for the good readers to go directly from print to the lexical entry. What is the nature of such visual configuration information? Some theorists characterize it as multi-letter visual features such as word shapes (Fisher, 1975; Rumelhart & Siple, 1972) or some types of familiar letter groups that are critical for whole word recognition without their constituent letters being identified (Baron & Strawson, 1976; Bauer & Stanovich, 1980). To demonstrate the existence of such visual configuration information, these investigators have employed the technique of presenting words arranged in alternating upper- and lower-case letter combinations. The purpose of mixing cases is to prevent readers from extracting the overall visual configuration information that is critical for whole word recognition. Results from most such studies, except those by Smith and his associates (Smith, 1969; Smith, Lott & Cronnell, 1969), have supported the availability of the visual configuration information by showing a large impairment of word recognition in mixed-case experiments (Coltheart & Freeman, 1974; Drewnowski & Healy, 1977; Mason, 1978; McClelland, 1976).

While the experimental evidence for the visual configuration information is undeniably convincing, the proposal that such information is available only for mature and good readers and only in high-frequency words has not been empirically verified. It has been taken for granted that the efficiency of such word-level visual configuration information is above and beyond the phonological pathway and is only a privilege of the good readers. In fact, there are experimental results which are at odds with such a conceptualization. We can also raise counter-arguments against this conceptualization based upon the data from beginning readers. For example, Shimron and Navon (1982) found that both children and adults were unable to resist grapheme-to-phoneme translation, that both children and adults benefitted from redundant information in their normal reading, and that children but not adults were sensitive to minor changes in graphemes which still preserved phoneme values. Thus, the argument that only good readers are sensitive to the visual pathway is certainly without much experimental support. But let us first take a look at results from experiments which directly manipulated the goodness of the printed arrays.

Suppose that good and less skilled readers are presented with words of alternating cases, what results should be expected from the viewpoint of a dual-access model? The prediction seems to be straightforward. A typical hypothesis had been advanced by Mason (1978) as follows: "Since mixed case serves to destroy any overall visual features a word may possess, one could expect highly skilled readers to be more distrupted by mixed case than less skilled readers, if highly skilled readers recognize words as wholes, whereas less skilled readers process individual letters." (p. 569). Mason ran a study to test this hypothesis but the results seemed to suggest the opposite: It was the less skilled readers who were the most disadvantaged with mixed cases. Confronted by such results, Mason had to conclude that less skilled readers were also using visual configuration cues but such information was a poor cue for accurate word recognition. The results and the inevitable conclusion in Mason's experiment present two important anomalies to the dual-access model mentioned above. First, the visual configuration information is not a privilege of the good readers. Second, it is not a strong cue for word recognition. What, then, is wrong with our conceptualization about basic reading processes?

There is an alternative interpretation for Mason's results, but that interpretation requires a different conceptualization of how various cues are put together to accomplish the recognition task. Again, let us postpone this description until we are sure about the replicability of Mason's results. There were only 12 good readers and 12 less skilled readers in her experiment. We decided to increase the sample size in each group. In the following experiment, good and less skilled readers were presented with 50 high- and 50 low-frequency words and were asked to name each presented word as soon as possible. Half of the words were presented in all lower-case letters and the other half were in mixed cases. The dual-access model predicts more disruption for good readers in the mixed case condition than for less skilled readers. Mason's results, if replicated, would require an alternative conceptualization.

Experiment 1

Method

Subjects. With the help of the Study Center at the University of California, Riverside, and of the Systemwise Project of Learning from Text, some 400 freshmen were administered the STEP II Reading Test designed for use at the college level. From these 400 students, 21 good readers and 21 less skilled readers were selected based upon their test scores. The good readers were selected from those who scored above the 90th percentile whereas the less skilled readers were selected from those scoring below the 40th percentile. These subjects were paid for their participation in the study.

Materials and Apparatus. Words used in this study were selected from the norms of Pavio, Yuille, and Madigan (1968). Fifty high-frequency (A or AA) and 50 low-frequency (0-5) words were selected with the following constraints: (a) Homophones were excluded, and (b) high and low frequency words were matched for concreteness (mean = 6.1), word length (mean = 6.6), and number of syllables (mean = 2.1). A lower-case and a mixed-case version of each word were typed on Mylar plastic and mounted on slides. For words presented in mixed cases, the letter combinations always started with lower case and then alternated between upper- and lower-case. The words were presented one at a time via a Kodak Carousel slide projector. A directional microphone and a noise-operated Hunter relay indicator, with sensitivity set at the maximum possible were used in conjunction with the projector equipped with a Lafayette tachistoscope shutter, and a Lafayette digital clock. The clock was activated when the shutter opened to display a slide. Elapsed time was recorded in milliseconds until the subject's initial vocalization, which terminated both the slide display and the clock.

Procedure. The subjects were tested individually and were told that they would see only words. They were informed about the nature of mixed-case words and were shown examples before the experimental trials began. They were asked to name each presented word as quickly and as accurately as possible.

Results and Discussion

The overall error rates were .059 for the good readers and .075 for the less skilled readers. Only the correct naming times were used to estimate the mean naming latencies of each subject under the four conditions (i.e., 2 levels of word frequency by 2 types of stimuli). The results of both skilled and less skillled readers are summarized in Table 1. Statistical ANOVA for a 2x2x2 (Readers by Frequency by Case) factorial design with first factor as a between-subject variable and the last two as within-subject factors was performed on the latency data. The results showed significant main effects of reading skill, F(1,40) = 55.44, MSE =26395.34, of frequency [F(1,40) = 82.39, MSE = 3237.14], and of case [F(1,40) = 208.87, MSE =678.09]. There is also a significant interaction effect between reading skill and word frequency, F(1,40) = 18.92, MSE = 3237.14, suggesting that less skilled readers are much more sensitive to the frequency effect. The interaction effects between reading skill and typecase as well as between frequency and typecase are both significant, F(1, 40) =31,42, MSE = 678.09, and F(1,40) = 113.65, MSE = 556.88, respectively. The three-way interaction is not significant. The above two interaction effects enable us to examine how reading skill interacts with case distortion and how frequency interacts with case distortion.

Insert Table 1 about here

Since we were interested in the magnitude of disruption due to alternating cases, the important measure to be examined was the time difference between naming the lower-case words and the mixed-case words. The mean differences of naming times for the good and less skilled readers are presented in Figure 1 as a function of the word frequency.

Insert Figure 1 about here

Now let us examine the results as depicted in Figure 1 with respect to several major questions of interest.

First, did subjects suffer from mixing cases? The answer is yes and for all subjects, including the less skilled readers. Second, did good readers show more disruption than the less skilled readers? Not at all and the picture is just opposite to the prediction from the dual-access model as described above. In fact, less skill readers show more disruption due to visual distortion than the skilled readers. In essence, we replicated Mason's (1978) findings. Finally did high frequency words have more disruption than low frequency words? Again, the answer is negative. Now let us focus only on the data of skilled readers naming high frequency words. According to the dual-access model, distortion of visual cues should have the most devastating effect on this condition. On the contrary, the data suggest that skilled readers do not seem to be bothered by mixing cases when the to-be-named word is a high frequency word.

In sum, the predictions generated from the dual-access model are not supported. A skilled, mature reader does not opt for the visual pathway as the sole source in order to be a faster reader. Rather, it is the less skilled readers who seem to have no choice other than adopting a visual configuration cue which is just not good enough for fast and accurate word recognition.

What went wrong with the dual access model of word perception? We think there are two erroneous assumptions that have been made in the model. First, it is not true that visual configuration information by itself can be a very effective cue. This can be seen in Groff's (1975) analysis of words found in school books which shows that less than 20% of the words found can be represented by a unique shape; consequently, the visual configuration information cannot be a useful cue. Second, it is doubtful that skilled and mature readers have ever bypassed the process of phonological recoding. We would suggest that it is the inability to utilize the phonological pathway that creates problems for less skilled readers. In an alphabetic writing system such as English orthography, the script-speech mapping represents a morphophonemic relation (Hung & Tzeng, 1981; Venezky, 1970). In order for a reader to be able to recode the printed word into its phonological representation, he/she must have developed some kind of "linguistic awareness" concerning the spoken language (see Mattingly, 1979, for a review) and he/she must be phonologically mature enough to be able to see the morphophonological regularities inherent in the script-speech relation of English orthography (see Fowler, 1981, for a detailed discussion on these concepts and their supporting evidence). Liberman, Liberman, Mattingly & Shankweiler (1980) have argued that these two special demands may account, on the one hand, for the elusiveness of the alphabetical principle in the history of writing systems and, on the other hand, for the frequent failure of learning to read among children.

When less skilled readers are unable to effectively utilize the phonological pathway, they can rely only on visual information such as shapes, certain idiosyncratic configurational cues (e.g., dog has a tail "g" at the end), or some familiar letter groups. For less skilled readers, any of these different types of visual information may be used to serve as memorial cues for word meanings and pronunciations (by rote memory, of course). Mixed-case presentation impedes the extraction of these visual features and thus results in severe disruption for the less skilled readers. In contrast, for good readers, the visual information is used as an additional cue to the already available phonological, semantic, syntactic, and other word-related information; thus, blocking the visual pathway would not result in any serious damage.

The above interpretation is largely based upon the assumption that there is differentiated and redundant information inherent in the printed words and that this information is only available to the good readers. If this account is a correct one, then we should predict that good readers will suffer more disruption when some of the redundant information is removed. The next experiment was conducted to test this prediction.

Experiment 2

In this experiment the attempt was made to remove some redundant information from the printed word which was again presented in alternating cases. Results from the last experiment showed that good readers were only mildly disrupted by mixing cases while less skilled readers were severely disrupted. We have taken these data to suggest that good readers are able to take the advantage of redundant information in the word whereas such information is not available to the less skilled readers. Our experimental strategy is to remove such redundancy and our expectation is that good readers should show more disruption due to the absence of the redundant information. The redundant information to be removed in this case is the spelling-to-sound regularity. Results from previous studies have demonstrated a facilitating effect of the spelling-to-sound regularity in tasks such as naming (Baron & Strawson, 1976; Glushko, 1979; Gough & Cosky, 1977) as well as lexical decisions (Bauer & Stanovich, 1980; Barron, 1979; Stanovich & Bauer, 1978). If we disrupt the printed array such that the distortion prevents skilled readers from quickly extracting the phonological information, then the facilitating effect observed in those previous studies should diminish or at least be reduced. We can achieve the visual distortion by alternating letter cases during word presentation, as in the last experiment. The question is how can we measure the effect of removing the regularity caused by mixing cases. We cannot simply look at the RT difference between namings of lower-case and mixed-case words. We need a control condition which we can use to gauge the magnitude of the effect of removing the spelling-to-sound regularity.

For this purpose we included another list of words which had irregular spelling-to-sound mappings. Reaction times for naming these words under both lower and mixed-case conditions were also measured and their difference was taken to set the baseline. Since irregular words can only be named based upon orthographic information, disruption caused by mixing cases can only be attributed to orthographic disruption. On the other hand, for regular-spelling words, mixing cases results in both orthographic and phonological disruption. Consequently, we should observe more disruption with regular-spelling words than with irregular-spelling words with respect to the effect of mixing cases on a naming task. Furthermore, this argument should apply only to skilled readers. For less skilled readers, the issue of phonological redundancy may apply to only a very small proportion of words. Thus, we should expect these readers to show quite a different pattern.

In Mason's (1978) experiments, both regularity and reading ability were varied but the expected interaction was not obtained. The null finding seems to question our interpretation. However, as cogently pointed out by Bauer and Stanovich (1980), several methodological weaknesses in Mason's study make it difficult to accept her results as concluding evidence. For example, exception and regular words were blocked in Mason's experiment. This procedure would certainly ensure that skilled readers would be able to adopt an orthographic reading, even for regular words. Also, Mason's experiment used Baron and Strawson's (1976) stimuli which were imbalanced with respect to word frequency (favoring exception words). These and other difficulties (see Bauer & Stanovich, 1980) render Mason's results inconclusive. In this experiment, we employed words used by Bauer and Stanovich (1980) to demonstrate a regularity effect. We also presented words randomly without separately blocking exception and regular words in groups.

Method

Subjects. Twenty skilled and 20 less skilled readers were selected from the same subject source as Experiment 1. None of them participated in the first experiment. They were paid for their service as subjects.

Materials and Apparatus. The stimuli consisted of 100 words adopted from Set A of Bauer and Stanovich's (1980) experimental words (listed in Appendix C on p. 431). The regular and exception words were matched on word length and word frequency (mean frequencies of 64.5 and 64.6, respectively according to the norms of Kucera and Francis, 1967). Lower-case and mixed-case versions of each word were constructed and mounted on 2x2 (inch) slide frames. In the mixed-case condition, the first letter of each word was always in lower case and subsequent letters in the word were in alternating cases. If one subject had a particular word in lower case, the next subject would receive the same word in alternating cases. The apparatus for stimulus presentation and for recording naming times were the same as in the last experiment.

Procedure. All subjects were run individually. The instructions for the practice trials and the experimental trials were the same as in the last experiment. Subjects were told about the nature of mixed-case words but were not informed about the regular vs. irregular aspect of the stimulus words.

Results and Discussion

Mean naming times were calculated for each subject for regular and irregular words for the lower and mixed cases. These data are presented in Table 2. Statistical analyses similar to those in Experiment 1 reveal significant main effects of reading skill [F(1,38) = 29.08, MSE =

35213.01], regularity [F(1,38) = 14.97, MSE = 4768.98], and typecase [F(1,38) =91.69, MSE = 1130.25]. There is also a significant interaction effect between reading skill and typecase, F(1,38) = 6.59, MSE = 1130,25. No other interaction effects are significant.

For each subject the time difference between naming a lower-case word and a mixed-case word was also calculated. Mean time differences for regular and irregular words are presented in Figure 2 as a function of reading ability. Let us examine these time differences with respect to our specific hypotheses.

Insert Table 2 and Figure 2 about here

With respect to the disruption caused by mixing the letters, do the good readers show a greater magnitude than the less skilled readers? The answer is no and this is consistent with the observation made in the last experiment. The significant interaction between Case Type and Reading Ability substantiates our position that it is the less skilled readers who suffer most from the type script distortion. For good readers, the distortion also slowed down their naming time, but to a much smaller degree.

With respect to the factor of spelling-to-sound regularity, we found that both good and less skilled readers were slower in naming the irregular words. Thus, we have extended Bauer and Stanovich's (1980) regularity effect on the lexical decision task to the naming task. It also suggests that Mason's (1978) failure to obtain such an effect may be indeed due to the fact that her regular words were contaminated by those which have inconsist "neighbors" (e.g., The word CAVE may activate its neighbor HAVE which happens to be a irregular word. For detailed arguments, see Bauer & Stanovich, 1980).

Now we come to the critical test: Did regular words suffer a double-disruption from mixed-case presentation (both orthographic familiarity and vocalic center pattern were destroyed) only for good readers? Although the expected three-way interaction did not turn out to be significant, the results as depicted in Figure 2 are certainly very suggestive. For good readers, we see more disruption in the regular words as compared to the irregular words, whereas for less skilled readers we see a completely opposite pattern. It would be difficult to explain the good reader's result in terms of a dual-access model. This model would assert that the visual route is the only way to read the irregular words, and consequently, disrupting the visual configuration should produce the utmost damage. Our data are certainly inconsistent with this prediction. In fact, this prediction is ironically confirmed by data from less skilled readers rather than from those of good readers. A more plausible explanation for all these results is based upon the concept of coactivation of various retrieval cues embedded in a printed word. According to this view, performance of word perception is facilitated when there are redundant cues (orthographic familiarity, vocalic center, word-length, letter position, etc.) which retrieve sub-word schemata to contribute to a common pool of activation that initiates a "word" recognition response. The fact that our less skilled readers did not show a double-disruption in the mixed-case presentation in naming the regular spelling-to-sound words strongly suggests that phonological information embedded in these words has not yet become an effective retrieval cue for them.

One question remains to be answered: Why was there a regularity effect for the less skilled readers? There are at least two possible answers. First, although our less skilled readers were unable to effectively use the phonological pathway, they were nevertheless on their way to gain access to this route. Second, the observed regularity effect may be purely due to orthographic familiarity. That is, exceptional words mean less occurrence with respect to a certain visual pattern. So the advantage may be accounted for by frequency per se rather than by less skilled readers' knowledge of phonological regularity. At this moment, we prefer this last interpretation.

General Discussion

The question of how a fluent reader processes printed words has been a key issue of experimental research in reading for at least 100 years. However, only recently have detailed models been worked out to relate some of their underlying mechanisms to the level of reading ability. Current reading models which incorporate the information processing approach have adopted a dual-access model to explain the results of different speeds in word naming and lexical decision between good and less skilled readers. In such a model, it is hypothesized that two separate pathways lead to the lexicon. One is accessed via a visual code while the other is accessed via a phonological code, with the visual pathway usually being the faster of the two (Bauer & Stanovich, 1980, p. 427). Since good readers are much faster in decoding words, it seems reasonable to conclude that they are visual readers in the sense that they tend to choose the faster visual route whereas less skilled readers can only rely on the slower phonological pathway. Similarly, the robust effect of word frequency on word perception is attributed to the activation of the visual pathway by the high frequency words.

While on the surface this account of individual differences in reading ability seems to be logically sound, further tests of hypotheses generated from the model yielded experimental results in a totally opposite direction. In fact, results from our two experiments with words presented in alternating cases strongly suggest that it is the less skilled readers, rather than the good readers, who are the visual readers and it is the low frequency words, rather than the high frequency words, which are more vulnerable to the distortion of visual configuration (this is especially true for the less skilled readers).

It is time for us to critically evaluate the basic assumptions underlying the conceptualization of the information processing model of reading, and the dual-access model in particular. These models are not at all unsophisticated and formulations of their various components are usually more than elegant. Why, then, are hypotheses generated from them so easily refuted by results from these very simple experiments of word perception. We think the most erroneous assumption made by the dual-access model is that the phonological pathway is readily available to both good and less skilled readers. In fact, we found only good readers able to utilize the phonological route as a backup system when the visual route had been blocked by mixed-case distortion. Recently, Katz and his student (personal communication) obtained experimental results consistent with our findings reported here. Theoretically speaking, in order to be able to utilize the phonological pathway made possible by an alphabetic writing system, a reader has to extract the grapheme-phoneme conversion rules embedded in that particular orthography. Mattingly (1979) and Liberman et al. (1980) have gathered much evidence to show that skilled readers differ strikingly both from illiterate adults (Morais, Cary, Alegria, & Bertelson, 1979) and from prereading children (e.g., Liberman, Shankweiler, Fischer, & Carter, 1974) along the dimension of linguistic awareness and of phonological maturity. Thus, it may be overly presumptuous to assume the readiness of the phonological route simply because every child seems to easily acquire the spoken language. Between script and speech, there is a gigantic gap to be crossed over. For many children and adults, this may not be as easy as it seems.

The second erroneous assumption made by the dual-access model is that good readers somehow bypass the phonological route and opt for the visual route. No doubt, visual configuration, familiar letter groups, word length, letter positions, and sequential redundancies, all serve as important clues to activate the "logogen" of a word (Morton, 1969). However, when the presented letter string has a regular grapheme-phoneme relationship, why the reader would want to avoid using this readily available information and thus bypass the phonological route is certainly a mystery. In recent years, information processing models also introduce the concept of automaticity (LaBerge and Samuels, 1974) to describe the speeding-up of many subskills (including letter-sound conversion) in word decoding by fluent readers. But if automaticity means no loss of processing capacity and no consumption of processing energy, then why is there any need for bypassing?

We propose that the difference between good and less skilled readers is that for the former there is a great deal of redundant information inherent in a printed word that is readily at their disposal and that this redundancy makes them less vulnerable to distortions in a presented letter string. For the poor readers, the lack of knowledge about the grapheme-phoneme conversion rules prevents them from the efficient use of the phonological pathway. They are then forced to adopt a visual reading strategy which is useful only when reading is limited to a very small set of words. As the number of words to be learned increases, confusions among words with respect to their visual configurations begin to set in and the visual reading strategy becomes the locus of the reading problem for these children. Thus, for most of these less skilled readers, the underlying reason for their inability to become efficient readers lies in their inability to make connections between script and speech in order to utilize the phonological pathway. If a once skilled reader suffers cerebral damage which prevents him/her from using phonology, then he/she has to rely on the visual pathway to get to the lexicon. But such a residual ability to use the visual cues to guess some of the words correctly in no way suggests that the visual pathway is a more efficient way of reading. The important fact to be remembered is that these patients read poorly and that is the reason that they are classified as "deep dyslexics". The data from deep dyslexics cannot, and should not be taken to support the assertion that good readers are visual readers. Rather, their error patterns in reading are consistent with our proposal that less skilled readers have difficulties in decoding words because they are visual readers.

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Footnote

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TABLE 1

MEAN NAMING LATENCIES (IN MSEC) FOR HIGH AND LOW FREQUENCY WORDS IN EXPERIMENT 1 AS A FUNCTION OF READING ABILITY AND TYPECASE

	HIGH FREQUENCY		LOW FREQUENCY	
TYPECASE	MEAN	ER	MEAN	ER
		SKILLED READING GROUP		
MIXED	604	.02	654	.057
LOWER	577	.015	610	.05
MIXED-LOWER DIFFERENCE	27	.005	44	.007
		LESS SKILLED READING GROUP		
MIXED	770	.016	906	.143
LOWER	708	.012	807	.10
MIXED-LOWER DIFFERENCE	62	.004	99	.043

NOTE-ER = ERROR RATE.

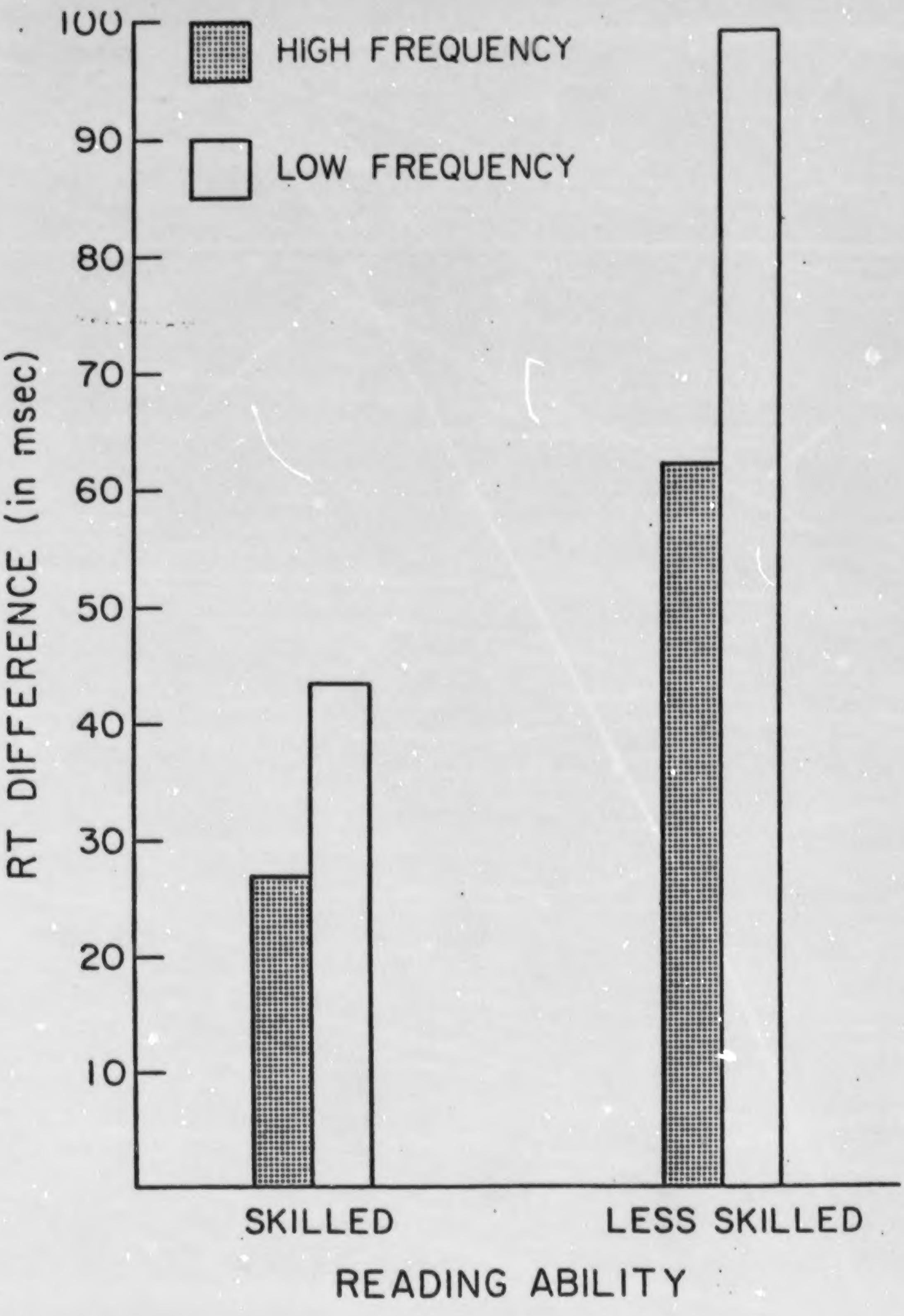

HIGH FREQUENCY
LOW FREQUENCY
RT DIFFERENCE (in msec)
100
90
80
70
60
50
40
30
20
10
SKILLED
LESS SKILLED
READING ABILITY

TABLE 2

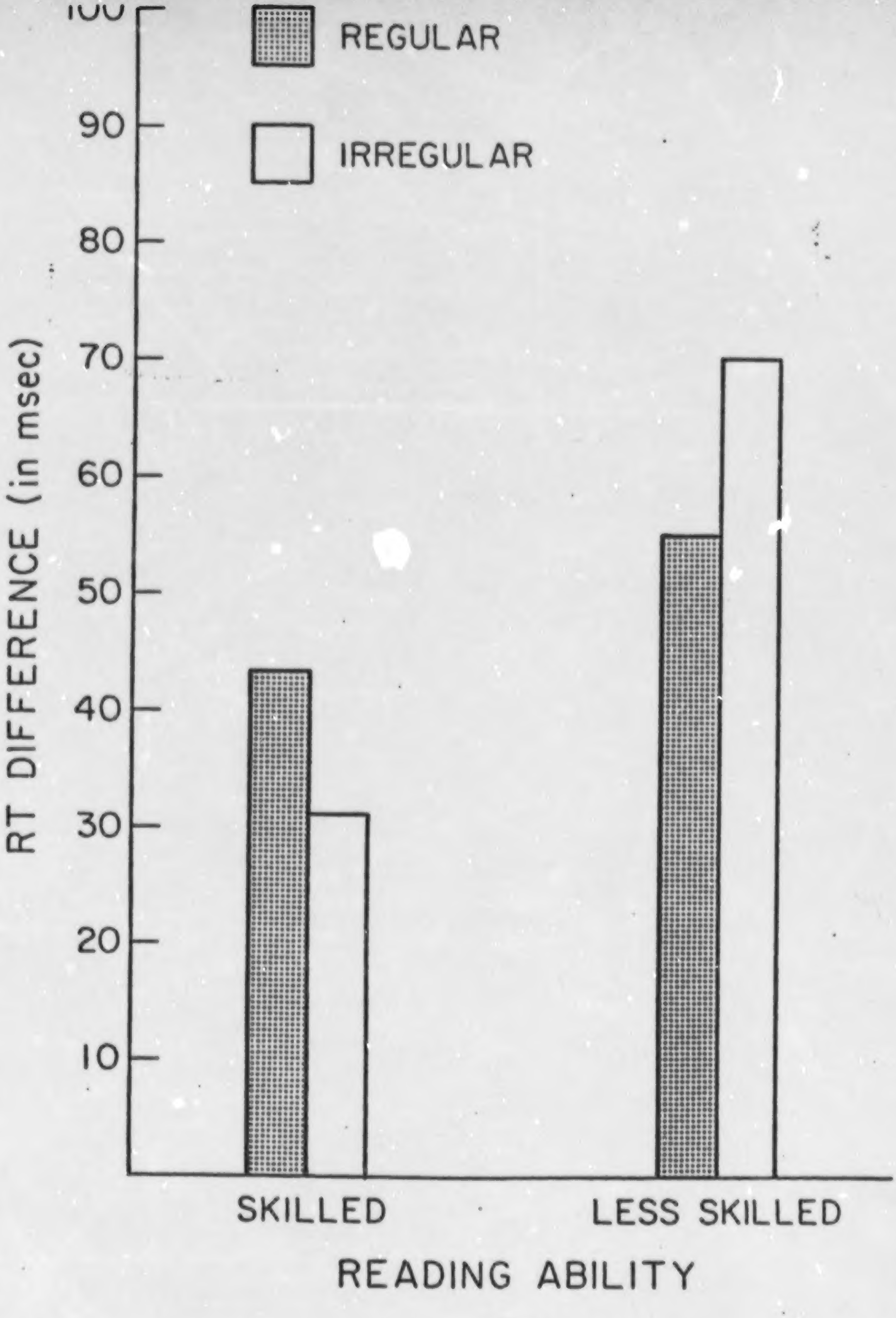
MEAN NAMING LATENCIES (IN MSEC) FOR REGULAR AND EXCEPTION WORDS IN EXPERIMENT 2 AS A FUNCTION OF READING ABILITY AND TYPECASE

	REGULAR	EXCEPTION
TYPECASE	MEAN	MEAN
	SKILLED READING GROUP	
MIXED	695	717
LOWER	652	686
MIXED-LOWER	43	31
	LESS SKILLED READING GROUP	
MIXED	849	911
LOWER	794	841
MIXED-LOWER	55	70

Figure Caption

Figure 1. Reaction time (RT) difference between naming lower-case and mixed-case words as a function of reading ability and word frequency.

Figure 2. Reaction time (RT) difference between naming lower-case and mixed-case words as a function of reading ability and grapheme-phoneme regularity.


REGULAR
IRREGULAR
100
90
80
70
60
50
40
30
20
10
RT DIFFERENCE (in msec)
SKILLED
LESS SKILLED
READING ABILITY

Chapter Five

Orthography, Reading and Cerebral Lateralization

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For most of us learning to read seems to be an easy task which really does not deserve much scientific attention. However, when one considers the proportion of children who fail to learn to read in the elementary school, it becomes clear that the success of learning to read does not come naturally, as does the analog of learning to speak. In fact, the shocking percentage of reading failure in many countries has led some researchers to conclude that "the problem with reading is not a visual perceptual problem; the problem is rather that the eye is not biologically adapted to language." (Gleitman & Rozin, 1977, p. 3). But the last statement cannot be right, for deaf children have no known problems learning sign language via the "visual" modality (Klima & Bellugi, 1979; Newport & Supalla, 1980). What, then, does contribute to the lack of success in learning to read? Let us examine the situation more closely.

The relation between written scripts and spoken languages seems so close that one would expect that anyone who is able to speak should be able to read. Nevertheless, this is not the case. Whereas all humans learn to speak effortlessly and naturally, indicating that there must be a significant influence from genetic facilitation, the situation is very different with writing. Many societies still do not have written languages; and in most literate societies, there are people who cannnot read or write, either for social or organic reasons. Thus, for cognitive theorists and practioners alike, the question becomes: Why do some children fail to learn to read? This question is particularly baffling when the reading failure is completely unexpected and defies commonsense explanations (Frith, 1981). For example, given that the child already has learned the spoken language, and that each letter on the printed array corresponds roughly to a visual analog of some known speech category, it seems that reading should be an easy deciphering task. Yet, this view is simply wrong. Decades of intensive research have revealed that the problem of reading may have something to do with the cognitive prerequisites to understanding one's own spoken language and to appreciating the script-speech relations embedded in a particular writing system (Gleitman & Rozin, 1977; Hung & Tzeng, 1981).

The recognition that purely external linguistic factors may contribute to the incidence of reading disability immediately brings our research focus onto several directions of inquiry. First, what are the linguistic factors which affect the process of learning to read at the entry level? Are they language specific? Second, what are the basic processing components in skillful reading? Again, are they language specific? Third, what are the defining features of reading disability and of acquired dyslexia? Finally, given the varieties of writing systems with different types of script-speech relations (Hung & Tzeng, 1981), how does the brain adapt to these orthographic variations? These and many other questions have been the central concerns of our research. Specifically, we have been trying to find out the ways in which different orthographies mediate between visual perception of a printed array and lexical retrieval. Given the linguistic differences in mapping the script onto speech, the three types of orthographies, namely, Chinese logographs, Japanese syllabaries, and English alphabet, seem to present different kinds of demands on their readers when they scan an array of print and attempt to convert the visual messages into some types of linguistic codes (Fowler, 1981). Such effects of orthographic variations are most apparent in the beginning readers (Gleitman & Rozin, 1974) as well as in the aphasic patients who have large left hemisphere perisylvian lesions (Coltheart, 1980). Thus, a comparative reading study across these three types of orthographies, with respect to both normal and dyslexic reading processes, would certainly help us to "unravel the tangled story of the most remarkable specific performance that civilization has learned in all his history." (Huey, 1908/1968, p.6).

In this initial step toward a comparative study of the reading process acros orthographies, we cannot hope to answer all the above questions. Instead, we wil focus on comtemporary research which is concerned with the cognitive an neuropsychological processes involved in reading. In particular, we will raise som key research questions and also point out what information is available and what is still needed in order to answer these questions.

A theoretical guideline would be helpful in sorting out the essentials from the messy data from most cross-cultural and cross-language research. It is our conviction that any attempt to understand the act of reading as a complex biological system should deal with the obtained data with respect to four sub-theories as suggested by Marshall and Newcombe (1981). First, we need to develop a theory of orthography which regards the theory of written language as a statement of the mapping between the form of an orthography and a set of levels of representation made available by virtue of having acquired the spoken language on the part of the beginning readers (Hung & Tzeng, 1981; Gleitman & Rozin, 1977; Wang, 1981).

Second, we need to develop a theory of perceptual learning that would specify which of the mappings that a certain type of orthography makes available are actually perceived and utilized by the beginning readers under various instructional programs (Gibson & Levin, 1975; Gleitman & Rozin,, 1977; Liberman, Liberman, Mattingly & Shankweiler, 1980). Third, a theory of modulation should be developed to specify the nature of the storage devices, transducers, feedback loops and so forth that are required to implement the on-line act of reading (McClelland & Rumelhart, 1981; Morton, 1979; Taft, 1979). Finally, we need a theory to specify the neuronal hardware that instantiates the dynamic aspect of lexical retrieval as exemplified in the above theory of modulation (Colthart, Patterson & Marshall, 1980; Marshall and Newcombe, 1973).

In this chapter, we will not attempt to give detailed specifications for each of the four subtheories. Readers who are interested in their developments should consult relevant journal papers as well as book chapters which are published in an increasing rate. Here are some leads. Wang (1981) has been trying to develop a theory of orthography from the perspective of an optimal orthography. Tzeng and his associates (Hung & Tzeng, 1981; Tzeng & Hung, 1980; Tzeng, in press) have attempted to specify the constraints of various script-speech relations on readers' linguistic awareness. They investigated the effects of orthographic variations on visual information processing (see also Leong, 1981). In another study, Tzeng, Hung, and Wang (1977) specified the role of speech recoding in reading Chinese logographs. With respect to the theory of neurolinguistics, Tzeng and his research group (Hardyck, Tzeng & Wang, 1977, 1978; Tzeng, Hung, Cotton & Wang, 1979) have looked into the issue of visual lateralization effect in reading different orthographic symbols. Recently, Hung and Tzeng (1981) have given an extensive review on various reading deficits in different types of aphasic patients and across different writing systems. The knowledge accumulated so far has enabled us to ask further questions concerning relations among orthography, reading and dyslexia. Let us look at some of the developments.

A. LEARNING TO READ AT THE ENTRY LEVEL

While the problem of reading disability is pervasive in languages adopting the alphabetic principle (e.g., English, German, Spanish, etc.), the rarity of reading disability at the beginning level has been noted in languages adopting syllabary and logographic systems (Makita, 1968; Tzeng & Hung, 1980). The ease of acquisition of the logographic system was further attested to by the widely cited study in Philadelphia with a group of second-grade school children with serious reading problems. These children continued to have problems even after extensive tutoring by conventional methods but were able to make rapid progress in learning and reading materials written in Chinese characters (Rozin, Poritsky, & Sotsky, 1971).

While the evidence appears impressive, one should be cautious in interpreting the results reported in the above studies. The study reported by Makita (1968) and the one cited in Tzeng and Hung (1980) were both crude survey reports. In both Japan and Taiwan where literacy is highly valued and a great deal of social pressure is always imposed upon schools to make the school look good, a simple survey on reading disability can never tell the whole story. Furthermore, different countries have different criteria for reading disabilities. As cogently pointed out by Stevenosn et al. (1982), the concept of someone possessing a "disability" is very difficult for Chinese and Japanese people to understand. In both cultures, retardation in reading would be attributed to lack of proper training and poor motivation. Thus, evidence such as that provided above cannot be interpreted too enthusiastically without appropriate cross-cultural controls. Rozin et al.'s (1971) results are interesting, but methodological weaknesses make them less impressive than they first appear. We think it is fair to say that so far no hard evidence has been provided to support the rarity of reading disability in a certain type of orthography (see also Stevenson et al., 1982).

To build our cross-orthography study on an empirical foundation, we should look into the problem of reading disability with respect to three specific criteria. First, we should examine the statistics of the general learning disability. Second, we should differentiate from the population of the general learning disabled the proportion of disabled readers who have problems specifically related to speech problems. Third, we should examine the difficulties of learning to read a particular orthography by those deaf children who have been deprived of speech. With respect to general learning disabilities, we should expect to find an independence between orthorgraphy and reading disability. With respect to the second criterion, we should expect to find that learning to read effectively is dictated by the special script-speech relation embedded in a particular orthography. In an alphabetic writing system such as English orthography, the script-speech mapping represents a morphophonemic relation (Hung & Tzeng, 1981; Venezky, 1970). In order for a reader to be able to recode the printed word into its phonological representation, he/she must have developed some kind of "linguistic awareness" concerning the spoken language (see Mattingly, 1979, for a review) and he/she must be phonologically mature enough to be able to see the morphophonological regularities inherent in the script-speech relation of English orthography. Liberman et al. (1980) have argued that these two special demands may account, on the one hand, for the elusiveness of the alphabetic principle in the history of writing systems and, on the other hand, for the frequent failure of learning to read among American children. Many other studies have also found correlations, ranging from .38 to .84, between phonemic awareness and learning to read English (Calfee, Lindamood, & Lindamood, 1973; Chall, Rosewell & Bloomenthal, 1963; Fox & Routh, 1976; Helfgott, 1976; Rosner & Simon, 1971). However, the direction of causality in these studies is controversial (Stevenson et al., 1982).

The third criterion listed above may be the only true test for the ease of learning a certain orthography. Without the experience of speech and now forced to learn a writing system which is parasitic on an unfamiliar spoken language, the deaf children's difficulties in learning to read are no surprise. The question is : Will they have a much easier time in learning to read Chinese as compared to learning to read English? We have a lot of statistics to suggest that deaf readers do not cope well in learning to read English (for a review see Hung, Tzeng & Warren, 1981). For example, in a large-scale study carried out in the U.S. in 1974, special version of the Standard Achievement Test was standardized on a sample of nearly 7,000 hearing impaired students. The median score on the paragraph reading subset reached a grade equivalent of about 4.5 among students aged 20 and above (Trybus & Karchmer, 1977). Comparable statistics are not currently available about the reading achievement of deaf children in Japan and Taiwan (or mainland China). However, there are reports from secondary sources which indicate that deaf children of these countries do not seem to have easier time than American deaf children in learning to read their respective writing systems. For example, Peng (1978) reported that among one quarter of a million or so deaf people in Japan, 25% are considered illiterate and the rest are considered as semi-literate. Similarly, in a book dedicated to the promotion of education for the deaf children, illiterate is also listed as the number one problem among the deaf population (Kuei, 1981).

Thus, althought precise statements are diffcicult to make, it does seem clear that there is no such thing as an easier orthography at the entry level of learning to read. Scripts, regardless of its orthographic principle, were developed maily to transcribe the speech at various levels. A deaf children, being deprived of speech, would have difficulty in attempting to decipher the script-speech code and that diffculty seems to be an universal one. However, this conclusion should still be accepted with caution since the data base from which the conclusion was drawn was only a very crude estimation. The picture is further complicated by the misunderstanding of sign languages and their relations to the written scripts. So, retardation of reading ability among deaf children may be due to inappropriate intervention programs and have nothing to do with orthography. Careful specification of the error patterns emerged during learning to read in order to get at the processes of how to integrate print with meaning remains to be done.

B. Hemispheric Specialization for Processing Written Language

There is reading disability in children that is known by a variety of titles, from word blindness, strephosymbolia, congeital alexia, specific learning disability, specific reading disability, and specific reading retardation to dyslexia, or congenital, specific, or developmental dyslexia. It is still not known whether it is a single syndrome or a loose collection of vaguely related disabilities. Some researhcers attribute children's failure of learning to read to the neuropsychological deficits of their cerebral organization (see Bradshaw & Nettleton, 1983, for reveiw). As mentioned before, orthographic variations embedded in the script/speech relations have to be accommodated by our brain. In this connection, specification of the interactions between orthography and cerebral organization can provide us important information concerning the neuropsychological pathways between print and meaning. This type of cross-language investigations at the neuropsychological level has just begun. However, experiments from last several years have already generated interesting and exciting reseults at both theoretical and practical levels (Hung & Tzeng, 1981; Tzeng, in press).

The human cerebral cortex is divided into left and right hemispheres, and presumably the two hemispheres function cooperatively in normal cognitive activities including reading. Nevertheless, the idea that these two hemispheres may assume different types of functions has been intensely studied over the last 100 years (see review in Hardyck et al., 1978). The term lateralization refers to the specialization of the left and right hemispheres of the brain for different functions. Experimental findings of and the rationale behind the visual hemi-field experiment and the actual experimental set-up have been reviewed by Hung and Tzeng (1981). Suffice it to say here is that in recent years there have been suggestions that learning to read different writing systems may result in different patterns of visual lateralization. For example, it has been observed that tachistoscopic recognition of phonetic-based scripts tends to show a right visual field-left hemisphere superiority effect whereas recognition of logographic symbols tends to show a left visual field-right hemisphere superiority (see Tzeng, Hung, Cotton, & Wang, 1979 for a review). A cerebral orthography-specific localization hypothesis has been proposed to account for these data (Hatta, 1977). This hypothesis was challenged by Tzeng et al. (1979) who found that, in fact, the left visual field superiority was only obtained with recognition of single characters and that a right visual field superiority similar to that obtained with alphabetic materials, was observed when two or more characters which make up a linguistic term were used. Tzeng et al. interpreted these differential visual lateralization effects as reflecting the function-specific property of the two hemispheres and rejected the orthography-specific localization hypothesis. Specifically, they argued for a left-hemisphere lateralized timing mechanism that is responsible for human language reading included. Let us examine this view more closely.

Duality of Patterning and the Three Ss.

Human beings communicate with language which assumes three different formats, namely, speech, sign language, and script. As communicative mediums, all these three Ss involve the manipulation of some motor gestures to transmit signals. For speech, one maneuvers his/her lip, jaw, tongue and larynx to shape the vocal tract in order to make various acoustic patterns (Wang, 1971). For sign languages, one moves and changes hand shapes through space to create multidimensional, layered configurations (Bellugi, 1980). Finally for script, one use handwriting and typewriting to capture his/her ideas and transmit them to readers (Hung & Tzeng, 1981). Hence, with respect to production, all three communicative tools require a neuronal mechanism for the selection, sequencing and timing of the motor commands. The consequence is a biological constraint imposed by the organismic structure of the signaling system whose evolution apparently lags behind the cultural evolution which proceeds at a much quicker pace and has developed in infinitely more directions. To resolve such a mismatch between the rates of biological and cultural evolution, our communicative system has adopted a sequential strategy at the signaling level and the result is the emergence of a most unique feature called "duality of patterning" (Hocket, 1960).

In a sense, the sequential strategy is a device chosen by the signaling system to overcome its biological limitations at both production (the vocal tract) and reception (the ears) (Mattingly, 1972; Warren, 1976) and meet the demand imposed by an ever increasing and expanding cognitive world. To appreciate this strategy, we need only take a look at how it works to increase vocabulary with limited elements. Suppose there are only two elementary states, say 1 and 0, in a signaling system, then by themselves only two cognitive events can be labeled. With the advent of a sequential property, these two elements can be combined to form four different states, namely, 00, 01, 10, and 11, resulting in four possible labels for four events. It can be easily seen that by producing these two basic elements in triplets, eight events can be labeled in the names of 000, 001, 010, 011, 100, 101, 110, and 111. Thus, with n-tuples, one can create a lexicon of 2^n entries. From this it can be shown that with m different elementary signals in sequences of length n, one can produce m^n labels to describe m^n cognitive events. It also follows that as the length of the sequences increases linearly, the potential size of the vocabulary increases exponentially. Therefore, the sequential strategy is an efficient way to achieve a large vocabulary with a limited number of basic elementary signals. Let us take a closer look at how the strategy is realized in human languages.

In his seminal paper, Charles F. Hockett (1960) pioneered an approach that uses "design features." These features allow us to see more clearly how human language has a basically distinct logical design from, say, the dance of the stickleback fish or the repertory of calls of the gibbon. One feature that was singled out to be unique to human communication is the adoption of the sequential strategy and in fact, this strategy is so powerful that all languages make double use of it. At the sentence level, every known language has thousands of words in its vocabulary which can be arranged in different sequences to form an enormous variety of different sentences. Similarly, at the lexical level, the various speech sounds in a language can be arranged in different sequences to form thousands of different words. At both levels, the meaning representation and the signal representation are kept separate, a feature called "duality of patterning." This feature makes possible mapping an immensely complex cognitive world onto a simple set of no more than several dozen motor gestures. The expressive power of language lies in part in the large number of possibilities in which these gestures may be sequenced. For example, the Englis words, TACK, CAT, and ACT, are totally distinct as to meaning, and yet are compose of the same three basic, meaningless sound segments in different permutations. Adequate understanding of any word, therefore, presupposes that the word can b distinguished from all other words that share the same phonetic property. In othe words, it implies a choice from among a set of phonetically similar words. If such choice was not made, it would not be possible to understand the meaning of a word.

Given the limited number of signals our motor/perceptual system can command and the ever growing size of vocabulary in the language, what is needed is a device which serves as the interface to join an intellect, which initiates, comprehends and stores an immense amount of messages, to the highly constrained signal production/transmission/apprehension system. The requirement for a sequential strategy in order to expand its information transmission capacity and at the same time to limit the signal length so as not to overburn the memory system becomes obvious. As Liberman and Studdart-Kennedy (1977) put it, "If we are to keep the number of segments per word within bounds, we must respect order: a word like /dam/ must be distinguished from its mirror image /mad/." (p.24).

There is, however, a price one still has to pay in using the sequential strategy: It undoubtedly takes longer to produce a sequence of n signals than to produce a single signal. In order for the sequentially organized signaling system to work efficiently, the signals must be produced very briefly and must follow each other in rapid succession. Since our vocal tract is primarily a group of devices for breathing and eating, a great deal of structural modification must have occurred as a result of coordinating the primary (eating and breathing) and secondary functions (rapid production of speech signals). Thus, unlike other animals, humans have evolved a complicated set of facial muscles that allow great mobility of the lips, cheeks, and jaw. They have also evolved a muscular and flexible tongue that can move freely in the mouth cavity. Moreover, they have teeth set side by side to form a barrier or ridge all the way around the gum so the ridges of the upper and lower jaw meet when the jaw is closed. Finally, the pharynx, the passage from the back of the mouth to the entrance of the lungs, is much longer than in other primates, thus increasing versatility of the vocal-tract filter (Lieberman, 1975). All these advances contribute to the possibility of making rapid speech signals with a co-evolving machine. (Note that the descent of the larynx into the neck was biologically risky. An elaborated swallowing reflex was required to prevent food from entering the lungs.) Apparently the human capacity for language has evolved in a way that not only exploits the sequential principle but also allows it to perform at an efficient rate.

We should suppose, then, then that the compromise is manifested in a phonology which restructured the information in the messages so as to make it compatible with our sound-signaling ability, and thus, match the pontentialities of the message-generating intellect to the limitations of the vocal tract and ear (Liberman & Studdart-Kennedy, 1977). In his recent award-reception address, Liberman (1982) has argued that for the speech code to be possible at such a phonetic level, two requirements are absolutely necessary: the phones must be communicated at a high rate and their order must be properly apprehended by the listener. In the conversion of absolute phones to concrete sounds, there is a restructuring of information such that the comprising segments would have their component gestures thoroughly intereaved. Such "coarticulation" enables a speakers to produce segments at rates considerably higher than the rates at which he/she must change the status of his/her articulatory muscles (Cooper, 1972). It also allow the listener to evade the limitation of the auditory system, Thus, the apparent advantage of the sequential strategy was further sustained by the property that increasing signal length anywhere near a factor of two per step does not require slowing down production, transmission and/or apprehension.

In a series of experiments, Richard Warren and his associates (Warren & Ackroff, 1976; Warren, Obusek, Framer & Warren, 1969) have demonstrated that human beings are very poor at recognizing the order of a short series of arbitrary sounds, such as a hiss, a high tone, a low tone, and a buzz. Even when each hiss, tone or buzz is 200 msec long (as long or longer than the duration of most phonemes), their subjects simply could not accurately recognize the temporal order of a fixed sequence of three or four such nonspeech segments. In contrast, a fluent speaker produces a phoneme about every 70 msec, a rate of about 14 phonemes or six syllables a second, and the listener is ready to perceive the stream of speech at such a rate without muc effort. Comparable rates of proposition transmission have been reported for sig language and speech (Klima & Bellugi, 1979), and it is well known that the rate o silent reading is much faster than that of speech. In fact, it is the sensitivity to time as for production and perception that characterizes the unique feature of duality of patterning in human communication. This type of information exchange must impose tremendous demands on both the production and perception systems responsible for resolving and maintaining the temporal sequences of input/output segments.

A Mechanism for Finer Temporal Resolution in the Left-Hemisphere

Over the past century or so, we have learned a great deal about the brain and about language. When the impairment of a linguistic function is highly correlated with damage to a particular region of the brain, the conclusion is usually that the function is served by the region. It is true that the evidence is abundant that not all brain tissues are equally involved in every mental behavior. Nevertheless, from studies of split-brain patients (Gazzaniga & Sperry, 1967; Zaidel, 1978) and of aphasic patients who suffered stroke, traumatic injuries, etc. (Lenneberg, 1967), it has been well established that for most people language appears to be located in the left hemisphere. In addition, this statistic has been confirmed by the results of injection of amobarbital into the carotid artery. Most of the cerebral hemisphere on the injected side is transiently anesthesized. In almost all right-handers and a majority of left-handers, the patient becomes unable to speak after left-side injection but not after right-side injection (Perria, Rosadini & Rossi, 1961; Milner, Branch & Rasmussen, 1964). This clinical observation is consistent with results from studies of normal right-handed subjects with experimental paradigms such as dichotic listening and visual hemi-field experiments.

Given the evidence for the cerebral lateralization of human language, the next logical step in the investigation of hemispheric specification is to identify the mechanism responsible for the lateralization. Decades of experimental and clinical observations, however, have not resolved the controversies as to which aspects of linguistic behaviors are responsible for this lateralization (Zaidel, 1980). The reason that past research has failed to answer this question may lie in the difficulties of first trying to sort out various aspects of linguistic information embedded in a string of utterances (or sign signals) and then to determine the critical one(s) that is(are) responsible for the driving force behind the lateralization. It should not be too hard to appreciate the complexities involved in the linguistic analysis of even a simple utterance: semantic, syntactic, phonetic, pragmatic and maybe other forms of information are always present as well as intricately related to one another. Nevertheless, it should not be too hard either to appreciate the fact that such complexity is the result of evolution since the time when our signaling system stumbled on a track which made it different from those of other animals. So, in considering the lateralization issue from an evolutionary perspective, it may be better for us not to worry about the many different new branches on the top of the grown-up tree; instead, we should focus on the root where our rudimentary form of the signaling system started its course. As cogently put by Francis Crick (1979), "There are often simple processes underlying the complexitie of nature, but evolution has usually overlaid them with baroque modifications an additions. To see through to the underlying simplicity, which in most instance evolved rather early, is often extremely difficult." (p. 232).

Among the three Ss, speech has been said to be the natural medium of languag and arguments have been put forth that humans have evolved structures an physiological mechanisms adapted for communication by speech and hearing. However recent studies on sign languages have revealed that the visual-manual languages tha have taken their own course of development as autonomous languages, yet nonetheles share many essential properties with spoken languages (Klima & Bellugi, 1979). So if we are looking for the root from which our communication system took its course the answer apparently cannot be the property which is modality specific in natur (Morton, 1980). What then is the critical feature which is common to all three S but distinctive with respect to those specified features in animal communication? have argued in the previous section that it is the feature of duality of patterni which entails a sequential strategy to be realized in a rapid fashion. In fact,

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we accept the contention that a sequential strategy as an interface device between the vast size of meaningful messages and the limited number of meaningless segments is necessary for the evolution of language, then we may further propose that realization of such strategy is responsible for driving the language function to the left hemisphere. Such a proposal is rather plausible at the physiological level: All we have to assume is that the two cerebral hemisphere differ in their rates of processing (as the result of, for example, differences in neurophysiological designs, see Semmes, 1968), with the left hemisphere showing finer acuity in temporal resolution (Hammond, 1982). All (or most of) other higher-level cognitive functions which show left-hemispheric dominance are no more than the elaboration of such differences in temporal resolution between hemispheres.

There is now ample neuropsychological evidence that such a mechanism for finer temporal resolution is localized in the left hemisphere. Damage to this mechanism not only disables patients' motor sequential behaviors but also impairs their lanquage ability in both production and perception (Albert, 1972, 1976; Efron, 1963; Goodglass, Gleason & Hyde, 1970). Results from these studies with aphasic patients imply that the left hemisphere is dominant for normal language because of its predominent capacity to retain and utilize the sequential aspects of acoustic inputs. Recently, using electrical stimulation mapping technique during craniotomy under local anesthesia for the resection of epileptic foci, Ojemann and Mateer (1979) were able to show that sequential orofacial movements and phoneme identification were altered from the same brain sites of the left hemisphere and thus identified a common system which processes elements both of language production and of language reception. These results are consistent with Mateer and Kimura's (1977) finding tht most aphasic patients, including those with predominantly receptive defect, show abnormalities in sequential control of oral movements.

Though the clinical evidence supporting a left-hemisphere temproal-based mechanism and its association with language behavior has been very impressive, the ultimate testing ground for neuropsychological theory should come from our ability to simulate neurological conditions, dissociations and deficits in the normal brain. Hence, it is important to look for evidence from the testing of normal subjects. Fortunately, a recent experiment by Tzeng, Hung, and Wang (1982) has shown unequivocally a robust effect of left-hemisphere dominance in coding the temporal sequence of linguistic materials. This experiment involves a specially developed technique of presenting letter sequences with a tachistoscopic recognition paradigm.

On each trial, there were three letters presented one by one onto the right visual field (RVF) or left visual field (LVF) of the screen within a Gerbrand 4-field Tachistoscope. To avoid backward masking, a 30 msec dark blank was inserted between consecutive letter presentations. The critical aspect of the experiment is the presentation location of each letter. Take the word CAT for example. The three letters C, A, and T were presented in that order. However, the letter C was presented in the center of the RVF (or LVF), the second letter, A, was presented 1/4 inch above the location where the first letter, had just been shown, and finally, the third letter T, was presented 1/4 inch below the location of the first letter. At any instance, only a single letter is shown on the screen. If subjects correctly integrate the temporal sequence, then they should report the word CAT. However, if they failed to code the temporal sequence, then there should be a high probability that they would report the word ACT instead because what was still available in their icon should be a string of letters arranged vertically as A, C, and T. For the purpose of clarification, Figure 1 shows a diagram which depicts the presentation sequence of a center digit and the three letters. It should be noted that whether o not subjects were successful in coding the temporal information, their response woul be a legal English word. Therefore, the experimental result would not be confounde by the response bias of "wordness." This aspect is also important in ruling out th possible confounding of different vocabulary sizes between the right and lef hemispheres.

Insert Figure 1 about here

Forty right-handed college students (20 males and 20 females) were recruited from the University of California, Riverside campus.

Tables 1 and 2 summarize the experimental results for male and female subjects respectively in terms of mean numbers of correct word reports according to the temporal order of presented letters as a function of visual field (LVF vs. RVF). In both Tables, the mean numbers of correct word reports according to the spatial order of the presented letters are also listed. The results are clearcut. For all subjects, regardless of sex, the ability to report the words according to the temporal order of the presented letters is higher when the letters are presented in the RVF than when presented in the LVF. The data were evaluated with dependent t-test and the results showed $t(19) = 5.96$, $p<.001$ and $t(19) = 4.65$, $p<.001$ for male and female subjects, respectively. If we collapsed the data across both sexes, then of the 40 subjects tested, only two (both females) showed minute reversals and four (1 male and 3 females) showed equivalent performance on both visual fields. The overall statistical analysis yielded a significant difference (21.62 vs. 26.43) strongly favoring the RVF presentation, $t(39) = 7.48$, $p<.001$. Thus, it is fair to say that compared with results from other visual hemi-field experiments, the most impressive aspect of the present set of results is the persistence of a RVF superiority across almost all subjects. It is also interesting to note that female subjects show a less stable pattern of left hemisphere lateralization while still maintaining the highly significant level of left-hemisphere dominance in temporal coding. This may suggest that a lesser degree of hemispheric cognitive specialization in females may be compensated for by greater activation of the hemisphere specialized for a particular task. Such a suggestion is shown in data of cerebral blood flow during cognitive activity (Gur, Gur, Obrist, Hungerbuhler, Younkin, Rosen, Skolnick and Reivich, 1982).

Insert Table 1 and 2 about here

The results of the above experiment demonstrated a left-hemisphere lateralized mechanism for finer temporal resolution. A follow-up study with exactly the same experimental procedure but replacing letters with colored dots was carried out by the same group of researches. It was found that no lateralization pattern was observed during the first block of 60 trials in which right-handed subjects attempted to identify the sequential order of the three colored dots. However, during the second block of another 60 trials, after subjects becoming more or less familiar with the range of possible permutation patterns, a left-hemisphere dominance was again observed at the significant level of .01. This result is important for at least three reasons. First, it indicates that results from the previous study with letters were not due to the claim that the left hemisphere seems to know more words than the right hemisphere (Kimura, 1961; Zaidel, 1976). Rather, the result suggests a different interpretation. That is, the reason for the left hemispheric superiority in word recognition is its greater ability at tracking the sequences of segments, regardless of whether they are audible sounds or visible patterns. Second, the result of the color experiment, taken together with the observation of severe deficit in manual and oral sequential movements among left-hemispheric lesion patients, also indicates that the temporally-based mechanism is amodal as well as prelinguistic in nature. Finally, the fact that the left hemisphere showed its dominance only after subjects gaining some familiarity with these stimulus patterns suggests that such a sequential coding is beneficial only when input stimuli become unitized. Thi particular feature of cerebral asymmetry provides the essential clue to th underlying mechanism for the lateralization of language to the left hemisphere. O the one hand, there is the requirement of the feature of duality of patterning i order to achieve a vastly increasing size of lexical units in human language. On th other hand, the finer temporal resolution power in the left hemisphere provides th opportunity for better sequential coding. It was only natural, then, that huma language emerged and evolved in the left hemisphere.

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In sum, these experimental results demonstrate a left-hemisphere lateralized mechanism for finer temporal resolution in normal right-handed subjects. This specific mechanism enables their subjects to keep track of the temporal sequence of the presented linguistic materials in order to form a word. Their result is consistent with the clinical observation that brain damage which leads to persisting language deficits usually include sites which had been identified as common to motor sequencing and phoneme identification. If duality of patterning is the most important design feature which makes human language distinctive from other animal communication systems, then these data and other clinical and neurosurgical evidence point to the hypothesis that the phylogenetic emergence of language is facilitated by a left-hemisphere timing mechanism which underlies both language (speech, script, and sign language) and sequential motor movements. It is probable that a precise timing mechanism would increase the survival capacities of the early hominids. Undoubtedly, successful hunting and fighting requires precise timing (even simple rock throwing requires precise timing to be right at the target). Thus, it is not a coincidence that handedness is an indication of hemispheric specialization and that it is one of the best predictors for language lateralization.

Implications

The idea that language lateralizes because it needs to take advantage of a precise timing mechanism in the left hemisphere helps to integrate most research findings concerning the cerebral asymmetry in processing speech. Ever since Kimura (1961) discovered a right ear advantage (REA) for dichotically presented verbal materials, investigators of hemispheric specialization have been trying to pinpoint the exact element in the verbal stimuli which is responsible for the left hemisphere superiority. A simple dichotomy of verbal versus nonverbal is certainly wrong. Several recent findings are particularly enlightening (see Cutting, 1974). First, it was found that the largest REA is produced when stop consonants /b,p,d,t,g,k/ are presented in pairs dichotically. Second, it was also found that liquids (i.e., /l/

and /r/) produced a less strong REA. Third, with steady-state vowels (such as /æ/ and /ɛ/) as stimuli, no REA was produced. Schwartz and Tallal (1980) notice that these stimuli not only belong to different phonetic classes, but also differ in the rate of change of acoustic cues that characterize their spectra (Liberman, 1982). They hypothesize that there may be a direct relationship between rapid temporal processing and speech processing and that such a relationship is responsible for REA. Indeed, in a dichotic-listening experiment with normal right-handed subjects, they are able to demonstrate that altering the temporal component of the acoustic spectra within a phonetic class results in a significant change in the magnitude of the REA. This finding, in conjunction with those mentioned above, strongly supports our contention that the superiority of the left-hemisphere for linguistic processing reflects left-hemispheric dominance in processing rapidly changing acoustic features by binding together phonetic segments so that at rapid transmission rates the temporal order and segmentation for speech may be preserved.

The specification of the importance of a left-hemisphere mechanism for finer temporal resolution has further implications for reading research. It has been claimed that a "culturally recent" and perhaps cortically overlaid language subsystem, such as reading, is particularly labile with respect to its cortical neuro-substrate and that its capacity is most likely associated with considerable anatomical variabilities of cortical representation (Hier, LeMay, Rosenberger & Perlo, 1978). It is also true that reading disability is widespread among the children of this country. Examinations of poor beginning readers reveal a common defect in immediate memory for item order, especially that associated with phonetic codes (Katz, Shankweiler & Liberman, 1981). It may be that some of these poor beginning readers are unable to utilize the left hemisphere timing mechanism to code the correct letter sequence in the printed array and thus are forced to adopt a right hemisphere reading strategy by reference to overall pattern recognition, but without access to the grapheme-to-phoneme correspondence rules (Witelson, 1976; also see Zaidel, 1980, for a similar point). In a recent study with experimental paradigm

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similar to that used by Tzeng et al. (1982) but with evoked potentials as the dependent measure, Bentin and Carmon (1983) were able to show that greater amount of brain activities occurred in the left hemisphere during reading, especially when a sequential strategy was employed by the reader to encode the input letters. It has also been reported that dyslexics have qualitatively and quantitatively different eyemovement patterns and characteristics from all other readers, not only during reading, but also in the simple sequential task of tracking sequentially moving light sources (Pavlidis, 1981). It is possible that such defects are results of incomplete cerebral lateralization (Orton, 1937; Zurif & Carson, 1970). Thus, further study of the interaction between hemispheric functioning and reading ability would shed light on the role of the timing mechanism in reading skills.

We have been trying to point out that the proposition of a left-hemisphere lateralized mechanism for finer temporal resolution is compatible with most experimental and clinical data on the production and reception of speech, script, and signs. A direct implication is that it is not the structure of language that is lateralized; rather, it is the processing mechanism to get at the structure that leads to the menifestation of a lateralized language. An indirect implication from such a proposition is that at a segmental level of language, such as lexical decision task, the right hemisphere may be able to perform some "language like" activities. The only differences are that it is slower and may use a totally different strategy (e.g., "ideographic" strategy) in word recognition. Zaidel (1983) has accumulated enough data on the "right-hemisphere language" to support this position. In fact, results of right hemisphere dominance in processing single Chinese characters can be used to argue for such an ideographic strategy.

Concluding Remarks

In this paper, our concern is with the issue of orthography, reading and higher cortical functions. Our ultimate goal is to find out the biological foundation of human communication with respect to the three Ss (i.e., speech, sign language, and script). On the one hand, while both speech and sign language evolve as primary linguistic systems, scripts was developed to transcribe mainly the former in terms of various orthographic principles (namely, logographic, syllabic, and alphabetic mapping rules). Consequently, learning to read presents tremendous difficulty to the deaf children who are deprived of the privilege of speech. On the other hand, both sign language and script are produced by hands and perceived by eyes, whereas speech signals are transmitted via the vocal tract and received by ears. Thus, modality specific properties of information processing seem to impose certain types of language cognitive constraints on the acquisition of these three different types of language skills. The communalities and contrasts among them are, of course, modulated by the brain. Therefore, discoveries of similarities and differences among these information processing systems within and across different cultures and languages should shed light on the functional organization of our brain. As the editors of the book, Deep Dyslexia, cogently put it, "Brain may be similar from one culture to another but orthographies certainly are not." (p. viii). So, we are in an era in which cross-language comparison of higher cortical functions in reading should reveal important information concerning how that same brain adapts to orthographic variations across and within different languages.